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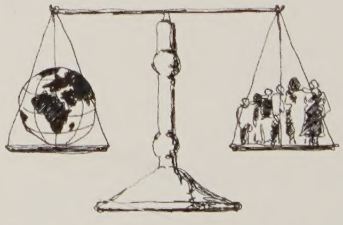

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Practical lessons for successful long-term cropping systems experiments

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Accepted 7 July 2010; First published online 18 August 2010 **Commentary**

Abstract

Many lessons in long-term cropping systems experiments are learned from practical experience. I have conducted large-scale, long-term, multidisciplinary dryland and irrigated cropping systems experiments with numerous colleagues at university and government research stations and in farmers' fields in the USA and in developing countries for 25 years. Several practical lessons learned through the years are outlined in this short commentary. While some of these lessons learned may be intrinsically obvious, results of many cropping systems experiments have not been published in scientific journals due to fatal flaws in experimental design, improper transitioning between phases of the experiment and many other reasons. Ongoing active support by stakeholders is critical to maintain funding for long-term cropping systems studies. Problems and unexpected challenges will occur, but scientists can often parlay these into opportunities for discovery and testing of new hypotheses. Better understanding and advancement of stable, profitable and sustainable cropping systems will be critical for feeding the world's projected 10 billion people by the mid-21st century.

Key words: long-term cropping systems experiments, crop rotations, world food needs

Introduction

Long-term cropping systems experiments are widely recognized as an ideal mechanism to encourage scientists of different academic disciplines to work toward a common goal[1]. There is a wealth of information on long-term cropping systems experiments related to agronomy, sustainability, environmental concerns, weeds and diseases, soil quality, fertility, economics and other factors[2,3]. There is also a vast quantity of information in the scientific literature and in textbooks on how to design and interpret data from long-term experiments. However, the 'practical' and 'everyday' aspects of successful long-term cropping systems endeavors have received much less attention.

I have spent the majority of my professional career as a cropping systems research agronomist in developing countries and in the Pacific Northwest region of the USA. There are some basic principles or 'lessons learned' from this experience with successful long-term cropping systems experiments that have not been adequately emphasized in the scientific literature and in university classrooms. The principles outlined below apply across diverse cultures and environments, whether: (i) the average farm size is 0.2 or 2000 ha, (ii) implements are pulled by bullocks or 450 hp tractors, or (iii) the grain is threshed by hand or with a fleet of modern combines.

Lessons Learned

1. Form a farmer advisory group of progressive individuals who have a strong vested interest in the research. Allow farmers to play an active role in designing crop rotation treatments. When farmers feel ownership in a project they are likely to remain strong supporters throughout the life of the project[4].
2. Set term limits for farmer advisors (e.g., 3–6 years). Some advisors make numerous valuable contributions and maintain a high level of interest, whereas others do not. The most valuable advisors are likely to agree to serve an additional term. Term limits provide a diplomatic means to end the service of the less energetic advisors and open opportunities for new members.
3. Collaborating scientists will largely determine the success of the study. Put a great deal of thought into what academic disciplines best contribute to the cropping systems team. Look closely at the publication record of experienced scientists. If an individual has an

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excellent track record, he or she will be likely to continue to publish regularly. Certainly seek out and mentor enthusiastic new-career scientists and encourage their participation.

4. Involve a statistician from the very first to ensure that the experimental design is valid and the most appropriate for the study[5].
5. Plan to conduct the cropping system experiment for at least 6 years or through two complete cycles of the crop rotations. Each crop in all rotations must appear each year for valid statistical analysis.
6. Ideally, systems experiments should have a staggered start to account for temporal entry into the rotation, but this is seldom imposed because it is not practical.
7. For a valid statistical interpretation of results, all crop rotation treatment combinations must have a common year denominator. For example, with 2-year, 3-year and 4-year crop rotations, the experiment needs to be conducted for 12 years.
8. Obtain and archive baseline soil samples at the beginning of the experiment so that changes over time in carbon, microbial activity and other soil quality indicators can be documented.
9. If possible, conduct long-term experiments at a university or government research station where land and facilities are guaranteed to be available[6]. Mistakes are less likely to occur at a research station than in a cooperating farmer's field. Labor and equipment resources are most efficiently utilized when travel and equipment hauling are kept to a minimum. It generally costs much less to conduct a cropping systems experiment at a research station than in a farmer's field. In addition, personnel at research stations are available to check the experiment daily, if needed.
10. If the long-term experiment is located on a farmer's field, do not expect a cooperating farmer to use and operate his own equipment to conduct field operations (e.g. planting, harvesting and herbicide application). This may be feasible for the first few years when the experiment is new and novel, but the farmer needs to manage his own field operations during the same time period and the experiment is not likely to receive high priority. Plan to provide your own personnel and preferably your own equipment to ensure that field operations are conducted in a timely manner.
11. Become a trusted friend of your cooperating farmer. Do not become a burden. Pay an annual rental fee for the land. List the cooperating farmer as a co-author on all popular and extension publications from the experiment.
12. Consider purchase or fabrication of smaller customized implements, such as no-till drills to facilitate the transport of equipment to and from sites and to reduce tractor size requirements.
13. Equipment may need to be customized for cropping systems experiments. For example, many cropping systems experiments involve conservation-till or no-till management. A small-plot combine is accurate for grain yield determination, but most machines lack proper chaff and residue spreading capability. Residue and chaff spreaders can be fabricated for small-plot combines[7].
14. Many cropping systems experiments do not contain enough treatments and/or replicates to provide adequate degrees of freedom for error to statistically detect treatment differences[8]. Try to maximize the degrees of freedom for error. Remember that the degrees of freedom for error are based on the number of treatments and replications.
15. When field operations or data collection cannot be completed in one day, always stop work for the day at the end of a replicate. This ensures that all treatments within a replicate are exposed to the same environmental factors (e.g., rain, heat and shattering) that may occur from one day to the next.
16. Funding for long-term cropping systems research is often difficult to obtain (and maintain), because answers cannot be obtained within the typical 3-year grant cycle[9]. Even modest set-aside funds from the university experiment station (e.g., Hatch funds) or other sources can go a long way in sustaining long-term experiments.
17. Long-term cropping systems experiments provide critically important data on soil quality[10], soil biology[11], carbon sequestration[12], nitrous oxide emissions[13], nutrient cycling[14] and weed ecology[15]. Such information is of interest to a worldwide audience.
18. If feasible, include a production economist on the team as economic returns of cropping systems are of foremost concern to farmers[16].
19. Be open to new ideas and view problems and surprises as potential opportunities. As an example, Rhizoctonia bare patch (*Rhizoctonia solani* AG-8) appeared in year 3 of a long-term no-till dryland cropping systems experiment in eastern Washington. The fungal root pathogen stunted all cereal and broadleaf crops in the experiment. Rhizoctonia bare patch at these high levels had not previously been encountered in the USA. Scientists decided to map the distribution of bare patches from year to year with a backpack-mounted global positioning system. The severe expression of Rhizoctonia bare patch was unexpected, but led to a unique opportunity to publish journal articles about the epidemiology of this pathogen under long-term no-till management[17].
20. Although scientists need to 'lock in' and stay with the crops and crop rotations throughout each phase of the long-term experiment, there is often an opportunity to superimpose new experiments, especially with wide plots. If the plots are narrow to begin with, options for future additional treatments are limited. Long-term cropping systems experiments continually generate new hypotheses to be tested. Embedding sub-experiments within a long-term study can be a good

way to obtain grant funding to support the long-term effort without comprising the integrity of the treatments already in place.

21. Hold field days at your research site. Scientists, graduate students, farmers and others involved in the experiment will welcome the opportunity to share their data, expertise and insights. Hands-on demonstrations, such as soil quality changes with different management practices, are popular and can carry an excellent take-home message. For field days at off-station cropping systems research sites, always feature the cooperating farmer as a key speaker as he will have important insights into what works and does not work on his farm.
22. Publish results in peer-reviewed journals at regular intervals. Decide beforehand which scientist(s) will take the lead on articles and the time frame when the articles will be written.
23. Do not stop with the publication of your research in a scientific journal article. Publish your research as an Extension Bulletin, Extension Video, or other popular format. Convert units of measurement to those used by farmers. For example, farmers in the USA use English, not metric, units. Delete unneeded verbiage (e.g., scientific names for plants and herbicides) and include interesting and relevant photos. Remember that you must obtain permission from the scientific journal in which the research was published before making the information available to stakeholders in an alternative format. I have never been refused permission by a journal to make information available in an alternative format for stakeholders. Many universities and government agencies have extension publication units that publish Extension Bulletins at no cost to the authors.

Conclusions

Following basic common-sense principles will help scientists achieve success in long-term cropping system experiments. As a research agronomist, I have collaborated most closely with a soil microbiologist, production economist, plant pathologist and soil physicist in cropping systems research endeavors. The specialty areas of scientists needed to address key issues will, of course, vary depending on the experiment. A major goal of the United Nations and other organizations is the widespread adoption of conservation agriculture[18]. To achieve this goal, more long-term systems experiments need to be conducted throughout the world. Long-term experiments provide the best and foremost scientific information for understanding the sustainability and stability of cropping systems.

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The use of vegetable subproducts from greenhouses (VSG) for animal feed in the Poniente region of Almería

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Abstract

The purpose of this research is to show that the vegetable wastes produced by the greenhouses of the Poniente region of Almería, which grow eight main horticultural crops, can be defined as vegetable subproducts and used for animal feed. These vegetable subproducts from greenhouses (VSG) meet existing legal maximum limits of waste from phytosanitary products at the European level, and they are free of other solid wastes. For this purpose, a farm must show that subproducts are traceable. The use of such VSG by sheep and goats would allow considerable reduction in biomass generated by vegetable greenhouses along with sustainable profit. At the same time, the cost of food for livestock would be reduced at a time when prices of fodder and concentrates are increasing. Finally, new traceability for vegetable wastes is proposed that would be compatible with and complementary to that existing nowadays, and would reduce the environmental impact of these wastes.

Key words: biomass from greenhouse, analysis of phytosanitary products, livestock feed

Introduction

The Poniente region of Almería is known worldwide for its specialty production crops. The eight main crops that form its agricultural tradition (pepper, melon, tomato, courgette, cucumber, watermelon, green bean and aubergine) occupy an area of 28,305 ha[1] in ten municipalities (El Ejido, Vícar, Roquetas de Mar, La Mojonera, Adra, Berja, Dalías, Felix, Enix and Darrícal) (Fig. 1). This horticultural area is 56.77% of the 49,786 ha of irrigated, vegetable crops of the province of Almería and 71.49% of the 39,593 ha occupied by the eight main crops mentioned previously. The cultivated area growing the eight main horticultural crops and subject to biological control amounts to 9813 ha[2] in the province of Almería, with 85.83% of the area (7882 ha)[3] included in the ten municipalities of Poniente (Table 1).

The Poniente region is also known for sheep and goat production. Of the total 4.41 million sheep and goats in Andalusia, 12.43% are located on livestock farms in the province of Almería[4]. These data are particularly important with respect to goats, because, of the total 1.13 million goats in Andalusia, 20.74% or 234,600 are in the province of Almería[4].

Therefore, a huge amount of biomass is produced in the vegetable greenhouses, estimated at 800,000 t of fresh vegetable material per year[5] or 1.10 million t[6]. According to the latest statistical data of the Delegación Provincial de Agricultura y Pesca de Almería (Provincial Government Office of Agriculture and Fish of Almería), and comparing the average data from the past two seasons, as well as consultations with agricultural technicians from the sector, the production of vegetable wastes coming from greenhouses in the province of Almería can be estimated at 1.95 million t, including 1.36 million t produced in the Poniente region of Almería. This biomass causes major environmental problems because it is usually accompanied by other wastes produced in greenhouses or inherent to such production, including raffia, containers and packaging, cover and padding plastic, wood and metal. These wastes,

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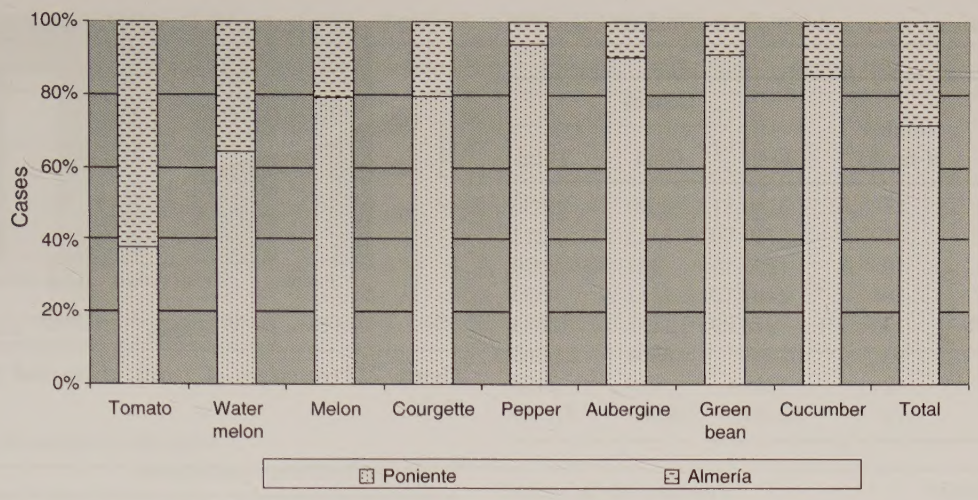

Figure 1. Vegetable area cultivated in greenhouses.

Table 1. Cultivated area of the main vegetables in the province of Almería.

	Tomato	Watermelon	Melon	Courgette	Pepper	Aubergine	Green bean	Cucumber	Total
Adra	138	451	421	96	385	170	94	106	1861
Berja	142	377	202	130	741	43	41	113	1789
Dalías	18	90	22	39	375	7	8	10	569
El Ejido	2113	1490	2546	2231	4269	434	1287	2273	16,643
La Mojonera	261	334	382	266	558	136	16	275	2228
Roquetas de Mar	516	163	312	278	668	100	71	269	2377
Vicar	605	120	167	311	700	460	71	404	2838
Poniente	**3793**	**3025**	**4052**	**3351**	**7696**	**1350**	**1588**	**3450**	**28,305**
Almería	**10,100**	**4696**	**5109**	**4210**	**8202**	**1495**	**1745**	**4036**	**39,593**
% Poniente/Almería	**37.55**	**64.42**	**79.31**	**79.60**	**93.83**	**90.30**	**91.00**	**85.48**	**71.49**

generated on farms where protected crops are grown, cause major deterioration in the quality of life of the adjoining environment. Solutions have been proposed for these problems, and include, among others, composting of vegetable subproducts from greenhouses (VSG) by aerobic biological decomposition under controlled conditions, using them as fuel to replace fossil fuels in cement plants through incineration, fueling energy generation plants through combustion of resources, and using them in overheated vapor or gasification[6] plants. The management of containers and container wastes seems more or less controlled by the deposit and return system, but management of biomass seems more complex, not only because of the technology to be applied but also because of the need for storage that prevents entry of animals and reduces the risk of deterioration. The use of this biomass as a subproduct in livestock feed might partially solve the problem, provided storage of this food can be properly managed. The main obstacle we find is the brief period of time in which it must be used by livestock before deteriorating, but such a problem can be solved with the use of a proper preservation method, such as silage[5], or with appropriate management.

The population is uneasy regarding consumption of these VSG by sheep and goats, because of rising concerns about possible biomagnification of supposed wastes of phytosanitary products in the brush or fruit coming from vegetable greenhouses. For this reason, it must be proved that the maximum levels of wastes in these subproducts are within the acceptable limits set by European legislation. All citizens should be informed about stockmen not opting for food dangerous to the livestock's health, because the use of dangerous feed would negatively affect their own economy in the medium or long term, although it supposes an economic profit in the short term. Furthermore, the use of VSG could help keep farms that, in other ways, would disappear over the medium or long term, because, on the one hand, of the owner's age (in some cases they are very close to retirement age), and, on the other, of the constant and progressive increase in prices of fodder and forage used to feed livestock. Finally, it must be stated that the evolution of biological control in the province of Almería contributes in a spectacular way to the confidence of stockmen in the use of this biomass as a subproduct of animal feed. It is enough to see that the area has grown from 130 ha (mainly of tomato and pepper) in the 2005/06

Table 2. Farms raising sheep and goats in the Poniente region of Almería[7].

Municipality	Number of farms	Census		
		Sheep	Goat	Total
Adra	17	3140	2690	5830
Berja	41	5750	5463	11,213
Dalías	10	1995	984	2979
Roquetas de M.	16	2401	2152	4553
Vicar	13	978	1855	2833
El Ejido	63	16,699	4864	21,563
La Mojonera	12	1219	979	2198
	172	32,182	18,987	51,169

season to more than 9000 ha in the 2007/08 season and more than 17,000 ha in the 2008/09[3] season.

Materials and Methods

In the Poniente region of Almería, in its ten municipalities (Adra, Berja, Dalías, Darrícal, El Ejido, Enix, Felix, La Mojonera, Roquetas de Mar and Vícar), there are 344 sheep and goat herds, with a census of 36,815 sheep and 25,840 goat for a total of 62,655 animals[7]. From census totals, 58,532 animals (34,457 sheep and 24,075 goat) do not correspond with fattening animals[7]. Fattening livestock do not use VSG; therefore, they were removed from the population under study.

Relevant veterinary services were consulted, along with data from the Delegación Provincial de Agricultura de Almería (Provincial Government Office of Agriculture of Almería), and it can be stated that there are some sheep and goat farms where feeding is extensive, and others are included in farms with temporary pastures used in transhumance; therefore, it seemed logical to also remove such livestock and farms from the population under study.

Likewise, it seemed reasonable to conduct a study of livestock with a census big enough to consume a significant quantity of VSG. We estimate the limit for such census at 50 animals; in this way, we eliminated all the sheep and goat herds of less than 50 animals, because we consider them not representative of the object of our research.

In this way, we obtained a final population of 172 farms with 32,182 sheep and 18,987 goats for a total of 51,169 animals, as shown in Table 2. Therefore, the initial population of our work was reduced to 50% of total herds (172 of the 344 initial ones) and 81.67% of the initial census of animals (51,169 sheep and goats from the initial 62,655). From this final census object of study, 62.89% were sheep (87.41% of the initial population) and 37.11% were goats (73.48% of the initial population) (Fig. 2).

The cultivated area of vegetables in the province of Almería amounts to 49,786 ha, of which 57.34% (28,547 hectares) is cultivated in the Poniente region of Almería[1]. The eight main horticultural crops are pepper,

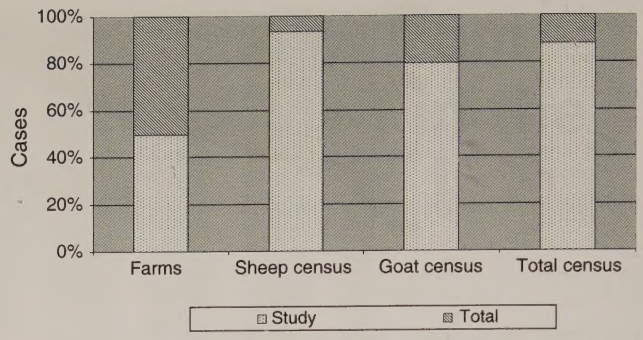

Figure 2. Percentages of farms, sheep and goats included in study.

Table 3. Confidence coefficients.

	Coefficient	% over 100	Adjustment
Melon	8	19.05	19
Watermelon	7	16.67	17
Green bean	6	14.29	14
Courgette	5	11.91	12
Aubergine	4	9.52	10
Tomato	4	9.52	10
Pepper	4	9.52	9
Cucumber	4	9.52	9
	42	100	100

melon, tomato, courgette, cucumber, watermelon, green bean and aubergine. The cultivated area subject to biological control of the eight main crops in the province of Almería comprises 9183 ha, of which 7882 (85.83%) are cultivated in the Poniente[3] region.

The data regarding area cultivated in the ten municipalities of the Poniente region of Almería, in terms of the eight main horticultural crops, appear in Table 1. The great importance of pepper crops (93.83%), green beans (91.00%), aubergines (90.30%) and cucumbers (85.48%) must be taken into account in the total area cultivated in the province. From these ten municipalities, we eliminated the municipalities of Darrícal, Enix and Felix because they are not representative.

At this point, we have a list of horticultural crops that can apparently be used for feeding sheep and goats. However, not all these crops have the same handling requirements, the same nutritive composition, or the same moisture content. Therefore, we applied a confidence coefficient reflecting the availability of the crop within the municipality where the farm is located, its nutritive content, its handling and management, and the amount of raffia or residual plastics left after harvest. In this sense, the most available and cleanest crop is melon, followed by watermelon, green beans and courgettes. Therefore, we created a weight scale where we assigned the highest weight, 8 to melon, 7 to watermelon, 6 to green bean and 5 to courgette. As the other four crops have a similar weight, we assigned a weight of 4 to each of them. We then transformed this total

Table 4. Importance in percentage of the use of each subproduct in terms of confidence coefficient.

	Tomato	Watermelon	Melon	Courgette	Pepper	Aubergine	Green bean	Cucumber	Total
Adra	3.64	14.91	10.39	2.86	5.00	12.59	5.92	3.07	6.57
Berja	3.74	12.46	4.99	3.88	9.63	3.19	2.58	3.28	6.32
Dalías	0.47	2.98	0.54	1.16	4.87	0.52	0.50	0.29	2.01
El Ejido	55.71	49.26	62.83	66.58	55.47	32.15	81.05	65.88	58.80
La Mojonera	6.88	11.04	9.43	7.94	7.25	10.07	1.01	7.97	7.87
Roquetas de Mar	13.60	5.39	7.70	8.30	8.68	7.41	4.47	7.80	8.40
Vicar	15.95	3.97	4.12	9.28	9.10	34.07	4.47	11.71	10.03
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 5. Nature of samples to be taken[8].

Classification of products	Examples	Nature of the primary samples to be taken	Minimum amount required
Fresh products of small size, units generally <25 g	Berries, peas, olives	Entire units or packing units, or taken with a sampling instrument	1 kg
Fresh products of medium size, units generally 25–250 g	Apples, oranges	Entire units	1 kg or at least 10 units
Fresh products of large size, units generally >250 g	Cabbages, cucumbers	Entire units	2 kg or at least 5 units

weight to a scale of 100 to obtain a coefficient referring to the highest confidence of the stockmen in one or another horticultural subproduct, to be called the confidence coefficient (Table 3).

The confidence coefficient can be applied to either the area of the subproduct with respect to the total subproduct in the region (Tables 1 and 4) or to the area of subproduct within each municipality with respect to the total area of each municipality. We chose the first option to make the work more representative. Thus, Table 4 shows the confidence coefficient for each subproduct with respect to the total corresponding subproduct and distribution in municipalities.

Once the importance of each subproduct was known in terms of confidence coefficients for sheep and goat feeding, a protocol for taking samples was designed to determine whether undesirable substances for animal feed were observed in the VSG. Therefore, it was decided to take samples of crops found on farms and used as livestock feed. Data included the types of vegetable subproduct found (whether brush or fruit), where they were physically found on the farm (in a warehouse or scattered on the plot), whether they had residues of plastic, raffia, or containers and packing, the traceability of such VSG (if they came from a greenhouse, the farmer's own or a fruit and vegetable handling center, a treatment center, or a spill of unknown origin) and the estimated amount in cubic meters, and for this purpose, a visit book was made. Once the action protocol was designed, it was decided to take 100 samples depending on the importance of each subproduct in terms of confidence coefficient for livestock feed, brush, fruit, or both, for each farm visited, with the purpose of analyzing multiple wastes in the Laboratory of Production and Animal Health of Córdoba, part of the Regional Ministry of Agriculture and Fish (Consejería de Agricultura y Pesca) of the Andalusian Regional Government, and in the Laboratory of Production and Vegetable Health of La Mojonera (Almería), also part of the Regional Ministry of Agriculture and Fish (Consejería de Agricultura y Pesca) of the Andalusian Regional Government. The purpose of these analyses was to detect the presence of residual phytosanitary products, forbidden and not forbidden, and to determine whether they exceeded the maximum limit on wastes established in accordance with regulations. Sampling was done completely at random, including the selection of farms, taking as a starting point the official legislation applicable to the sampling methods for the control of pesticide wastes in products of vegetable and animal origin[8,9] (PNT-04MA22 and PNT-04MA30—Method Validation and quality control procedures for pesticide residues analysis in food and feed. Document No. SANCO/2007/3 131.31/October/2007. Supersedes Document No. SANCO/ 10232/2006). Products of vegetable origin, a description of primary samples, and the minimum size of laboratory samples appear in Table 5. The minimum sample amounts varied depending on whether brush or fruit was being sampled. In this sense, for brush, 200 g samples were taken in a closed bag. Samples had two labels. Bags were labeled with one specifying the code of the farm, owner of the farm, location of the farm and number of the sample. In the case of fruit samples, if they were large (melons, watermelons, aubergine, cucumbers and courgettes), five fruits or 2 kg of weight was taken; if they were small (tomatoes, peppers and green beans), ten fruits or 1 kg of weight was

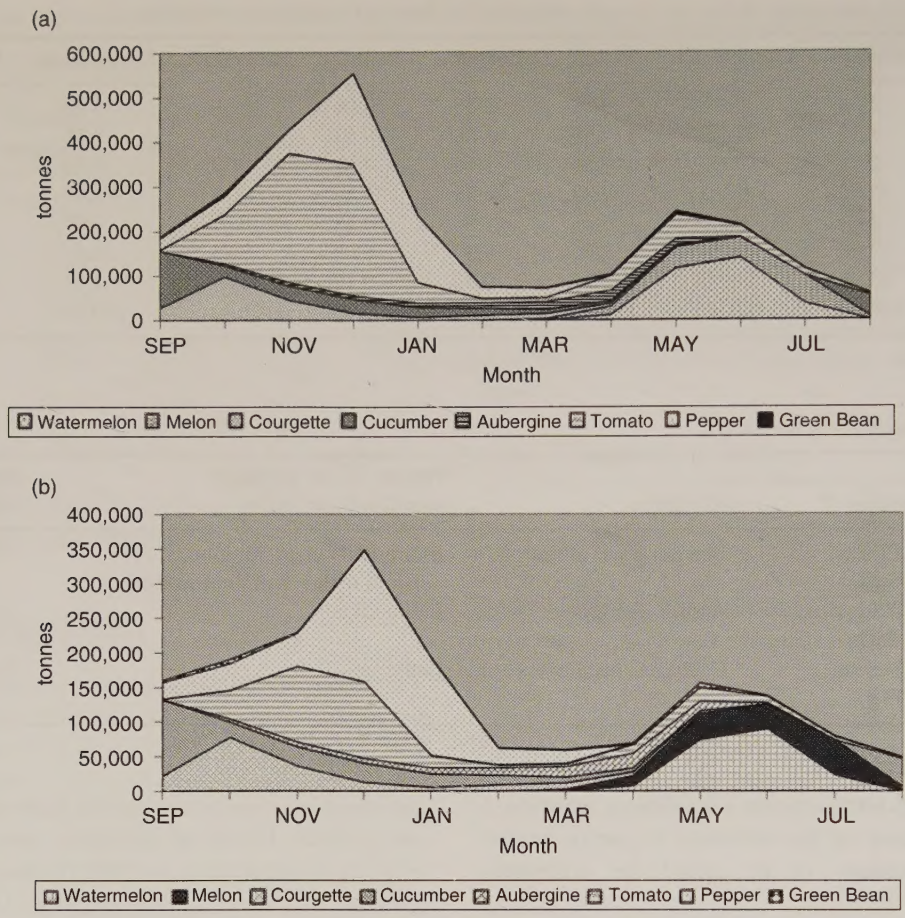

Figure 3. (a) Production of vegetable wastes by greenhouses in the province of Almería by months. (b) Production of vegetable wastes by greenhouses in the Poniente region by months.

taken, with samples put in bags similar to those used for brush. The second label was added to the sample sheet to unambiguously identify the sample.

Once the protocol for taking samples was developed, a visit schedule was prepared and the places to be visited were mapped. For this, the approximate dates of generation of subproducts were taken into account in the different municipalities during the year (shown in Fig. 3a and b), along with the importance of each subproduct in terms of confidence coefficient for sheep and goat feeding. The visit schedule is shown in Table 6.

Results and Discussion

Of the 39 samples sent to the Laboratory of Production and Animal Health of Córdoba, 37 (94.87%) appeared free of wastes of undesirable substances in animal feed (Fig. 4). The other two samples, from brush, showed wastes of undesirable substances over the maximum limit of allowed wastes, but this does not imply that within an appropriate safety period, even those two samples could not be used for animal feed. It must be highlighted that undesirable substances never appeared in fruit. We grouped the results of the samples sent to the Laboratory of Production and Animal Health of La Mojonera (Almería) into two parts, fruit and brush. Further, we considered them separately in order to better represent the different types of analyses carried out. The differences in feed composition are due to fruit and brush coexisting for a period of time on the farm, waiting for consumption by livestock. In addition, compulsory legal measures against disease in horticultural crops[10] state that *once the crop has terminated, when the plants are pulled up, greenhouses will be closed and stay closed until plants are completely dry, treatments applied against vector insects, and vegetable waste properly removed, and abandonment of the crops is totally forbidden.* Wastes of phytosanitary products undesirable for animal feed appeared only in brush, but a logical explanation can be given. From the results obtained, those results less than 0.05 part per million have been eliminated because they appeared only in brush and may have been caused by derived products (endosulfan), by metabolic transformations (carbendazime), or even by compulsory treatment of the greenhouse harvest waste, before being considered as VSG, as mentioned.

Of the 90 samples of fruit sent to the Laboratory of Production and Vegetable Health of La Mojonera, 89 were free of undesirable substances for animal feed, and no

Table 6. Visit schedule % for subproduct and municipality.

	Tomato	Watermelon	Melon	Courgette	Pepper	Aubergine	Green bean	Cucumber	Total
Adra	0	3	2	0	0	1	1	0	7
Berja	0	2	1	0	1	0	0	0	4
Dalías	0	1	0	0	0	0	0	0	1
El Ejido	6	8	12	8	5	3	11	6	59
La Mojonera	1	2	2	2	1	1	0	1	10
Roquetas de Mar	1	1	1	1	1	1	1	1	8
Vicar	2	1	1	1	1	3	1	1	11
	10	18	19	12	9	9	14	9	100

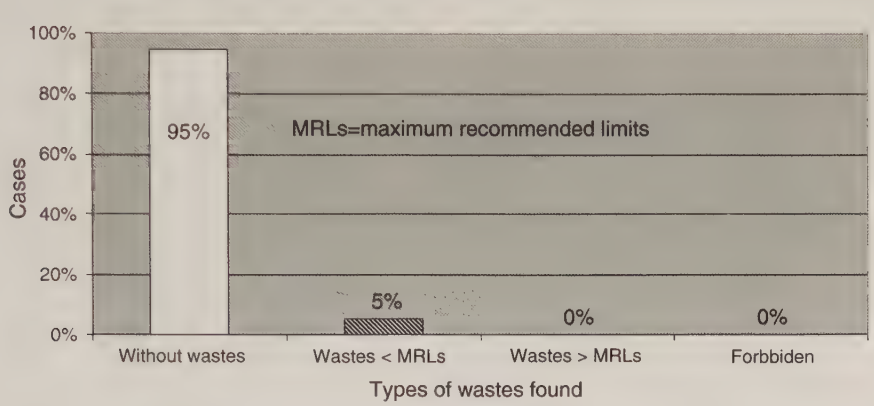

Figure 4. Types and amounts of wastes and undesirable substances found in VSG.

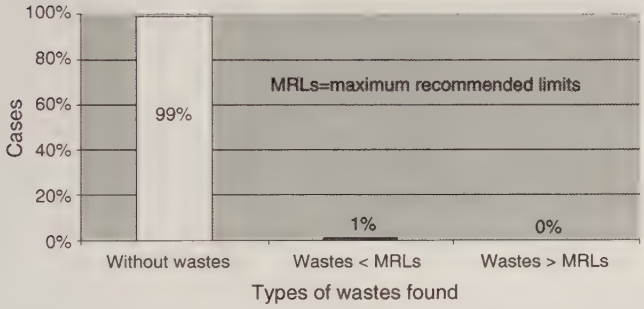

Figure 5. Types and amounts of wastes and undesirable substances found in fruit.

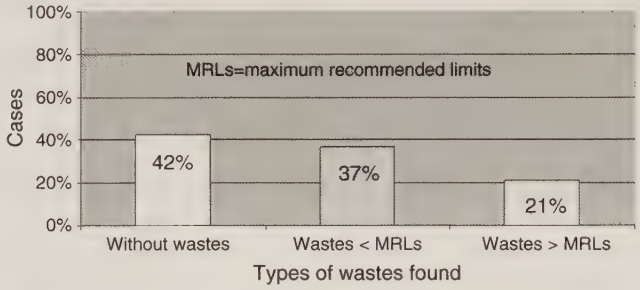

Figure 6. Types and amounts of wastes and undesirable substances found in brush.

samples contained forbidden substances (Fig. 5). Of the 109 samples of brush sent to the laboratory, 45 (42.2%) were free of undesirable substances, 40 showed wastes of phytosanitary products above the maximum limits allowed in human feed but not for animal feed (they were free of them) (Fig. 6). With a proper safety period, they could be used for feeding herds. Finally, 23 samples showed forbidden substances (not undesirable) for animal feed, mostly due to soil treatment (endosulfan), to active substances that were recently forbidden (malathion and procimidone), or to the compulsory treatment of vegetable waste.

In the 86 visits made, 178 samples were taken, controlling a total of 288 subproducts, of brush as well as fruit. In particular, a total of 194 subproducts from brush and 94 from fruit were controlled. In the 288 subproducts, raffia was found in 28% (Fig. 7), especially in tomato, courgette, green bean and pepper, appearing in very small amounts in melon and watermelon; however, the presence of plastics on the farm, as well as containers and parts of containers, was practically 0% (Fig. 7). The presence of plastics or containers makes livestock feeding more difficult; therefore, stockmen try everything possible to remove them when they find them among vegetable subproducts. In 44% of cases, the VSG were scattered in the plot constituting the farm or in other plots located in surrounding areas where

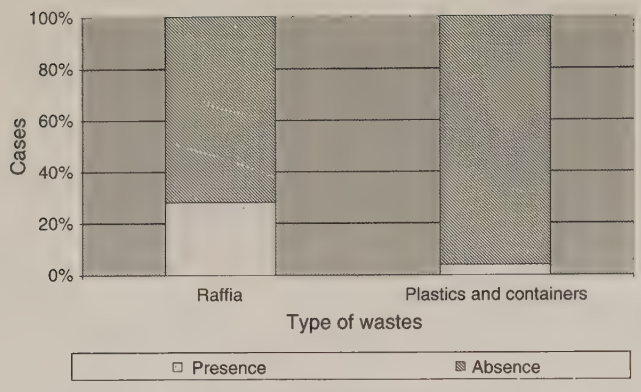

Figure 7. Types of packing wastes found on farms.

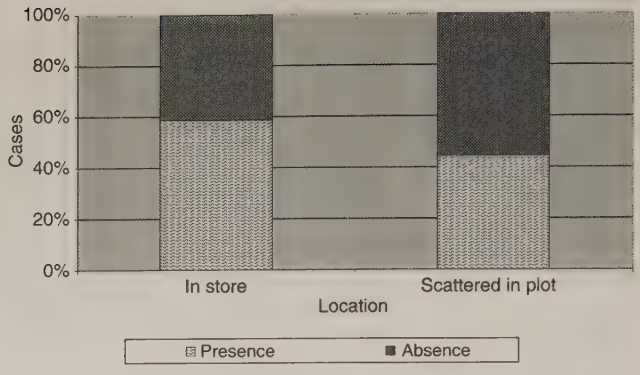

Figure 8. Location of VSG on farms.

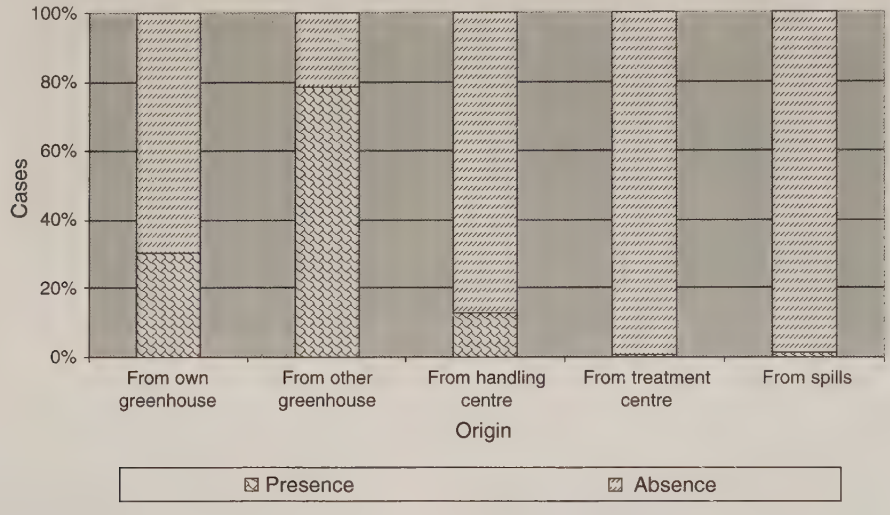

Figure 9. Origin of VSG on farms.

Table 7. Model of traceability log for VSG.

VSG USED IN SHEEP AND GOAT FEED							
Owner of farm:						**Farm code:**	
Address of farm:						**Sheet no.:**	
Date of entry	Provider	Type of VSG (brush/fruit)	Species	kg or volume.	Date of results of multi-waste analysis	Signature of provider	Signature of receiver

stockmen scattered brush or fruit to feed livestock (Fig. 8). The problem with scattering fruits in unfenced plots is that insects such as flies and mosquitoes proliferate, in addition to rodents, and keeping the animals in the vicinity can be difficult. Therefore, it is not recommended that fruits be used for livestock feed if the plot is not cleaned immediately after the herds have eaten. In 77% of cases, the VSG came from greenhouses other than those owned by the stockmen, and comprised mainly melon and watermelon crops, as shown in Fig. 9.

The results of this study support the use of these VSG in sheep and goat feeds; however, planning in this sector is not occurring nationwide, unlike the situation in other sectors, such as that of pigs, where the traceability system for pig manure is well developed, and pig manure is authorized for use as an organic fertilizer[11]. Legislation does not exist in our sector of study. There are no rules regulating the characteristics of sheep and goat farms with respect to their infrastructure or to maximum numbers that a farm can accommodate. In the pig sector, there are legal limitations that protect pigs; for example, fattening pigs between 20 and 100 kg of live weight require at least 0.65 m^2 of space per animal. This means that farms are never smaller than allowed and that accommodations for herds can be perfectly structured, including places for their daily exercise, places for feeding, growing, breeding, etc.

In the case of sheep raised for meat, only practical hygiene guidelines are in place[12–14]. These guidelines suggest the following European Community[15] and national[16] recommendations for fodder hygiene. Since sheep are ruminants, they require long fiber for proper digestion in their rumen, and such fiber may be provided by the brush in VSG. The guidelines also state that they eat the most appetizing food first, usually the food with the highest energetic concentration; therefore, this aspect should be taken into account when portions are shared. Likewise, it is also recommended that farmers keep a record of all necessary data pertaining to control of the fodders entering the farm, including date of entry, provider, delivery note, type of fodder, prescription number in the case of medical fodder, and the animals to which such fodder is given. It also seems reasonable to keep a traceability record of VSG, registering stockmen of origin, date of entry, vegetable species, approximate kg or volume, provision of multi-waste analysis proving that no wastes of phytosanitary products are included or that the existing wastes do not exceed the maximum recommended limits (MRLs). A model traceability log is shown in Table 7.

With respect to storage, the guidelines of the Spanish Ministry of the Environment and Rural and Marine Affairs state that feed for livestock must be stored in conditions of low humidity and proper hygiene. There are cases where the VSG are transported from a greenhouse or even from a horticultural center to the farm, where, with no type of traceability control, they are spilled on the plot, and many times such a plot does not belong to the stockman. In this case, neighbors usually make formal complaints about insects, bad odor, putrefaction and the waste traditionally known by stockmen as *churre* (dirty grease) that can cause problems with percolation and contamination of subterranean aquifers. At other times, brush is stored far from the soil and thus free of humidity; however, it could be covered with plastic to protect it from the open air. The effect of excess humidity is usually the presence of fungus and mold, decomposition and odor.

The problem of separation of raffias can be easily solved in two ways. One is by use of a mechanism placed on the front of the tractor that would lift the brush and separate out a large portion of raffia. The second way is by using natural biodegradable raffia, an alternative to polypropylene that creates totally organic waste without affecting the production of crops, even in the case of long-cycle[17] crops.

Finally, it must be stated that Andalusian regulations pertaining to farms[18] affirm that all farms must use means of production that guarantee keeping the farm at a proper hygienic and healthy level and that allow effective cleaning, disinfection and elimination of insects and rodents. Animal welfare regulations in force[19] must be observed. Animals must be kept in an enclosed and delimited area, so farms that use VSG are normally enclosed, but they use bordering plots to scatter the feed (fruit and brush) so that when the herds go out to exercise, they eat at the same time. This practice is normal in the Poniente region of Almería, and it is the object of many complaints by individuals. The problem can be easily solved if the correct hygiene, animal welfare and food provisions are observed, and if the plots on which such food is scattered are enclosed, preventing access from the outside, and all remaining feed is removed after the livestock have finished eating.

Conclusions

In view of the results, we conclude that brush and fruit VGS from the eight main crops grown in the vegetable greenhouses of the Poniente region of Almería is a potential feed stock for sheep and goat herds in the region. Precautions must be taken to avoid the use of brush VGS that contains higher than permissible levels of phytosanitary products, or levels of packaging waste that would endanger the health of the livestock. Considering the high prices of raw materials that compose the fodders and concentrates used in sheep and goat feed, VGS provides a viable, low-cost substitute or supplemental source of nutrition for sheep and goats in the Poniente region of Almería.

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Moving local food through conventional food system infrastructure: Value chain framework comparisons and insights

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Abstract

There is growing recognition that the direct marketing initiatives favored by many local food activists and proponents often lack the capacity to meet rapidly expanding consumer demand for local food. To address these needs, some food systems researchers have identified a role for 'transitional' food systems that piggyback on the pre-existing, conventional local food system infrastructure, while moving toward the social and economic benefits of direct marketing. This paper uses a value chain model (based on business management studies and adapted to the context of agrifood enterprises) as a framework for investigating how actors who are accustomed to working within the logic of the traditional produce industry incorporate local food into their overall operations. Using a qualitative comparative case study approach, the paper examines how features of the value chain structure and governance mechanisms operate in two food distribution networks that are transitioning toward localization in a rural and an urban region of Pennsylvania, respectively. Case study analysis focuses on conventional wholesale produce distributors as the link between local producers and local buyers. Interviews with the distributors, producers and buyers reveal the sources and outcomes of challenges affecting how the distributors organize their purchasing and selling of local produce. Network practices, in turn, have equity implications as distributors struggle to pay producers enough to maintain their economic viability, while still making local produce accessible to a wide range of consumers. Policy-makers and practitioners seeking to support the 'scaling up' of local and regional food systems should consider targeted development of technical infrastructure in processing and distribution, as well as outreach on appropriate shared ownership models. Future research should be longitudinal to determine the longer-term role and contribution of the conventional food system infrastructure in transitioning to more sustainable local and regional food systems.

Key words: differentiation, distribution, local food, regional food system, value chain

Introduction

Interest in local food has exploded over the past few years. Although much of this interest has been expressed in direct marketing enterprises, such as farmers' markets and community-supported agriculture (CSA), recent efforts have addressed broader aspects of restructuring the food system to have a more local or regional focus. For example, under the Obama administration, the USDA has created the Know Your Farmer, Know Your Food initiative, designed to funnel funds into pre-existing programs, but with a renewed emphasis on local food. One of the USDA's public statements says that this program, 'promotes local and regional food systems by stimulating community and economic development and ensuring equitable access to affordable, fresh and local food'[1]. While much of this funding is aimed at the traditional thematic areas of rural development and agricultural marketing, there is also recognition that communities are grappling to coordinate local production and distribution with increased demand. To address these needs, some food systems researchers have identified a role for 'transitional' food systems[2] that piggyback on the pre-existing, conventional local food system infrastructure, while moving toward the social and economic benefits of direct marketing. However, achieving these benefits outside the context of direct interactions between producers and consumers may be challenging, since most conventional food businesses are situated within the very system that direct marketing aims to challenge.

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Value chains offer one model for restructuring regional food systems that operate at a larger scale than direct marketing while deliberately embedding mechanisms to ensure social, environmental and economic benefits for supply chain participants. Originating in the business and supply chain fields of study, the value chain framework has been adapted for the agrifood system by Stevenson and Pirog[3] as part of their work with the U.S.-based Agriculture of the Middle task force[4]. In this context, value chains refer to the businesses involved in each stage of the supply chain from field to table. These business relationships are distinguished from traditional supply chains by focusing on value-added products and value-based interactions that add an ethical component to economic exchange. Yet the value chain model also incorporates issues of scale and efficiency, which are crucial for addressing the problem of low margins in many agricultural production systems[5].

In this paper, we employ Stevenson and Pirog's value chain model as a heuristic framework to analyze how food distributors who are accustomed to working within the logic of the conventional produce industry incorporate local food in their overall operations. We are particularly interested in the organizational and equity implications of these practices. We use the value chain structure and its governance mechanisms as points of comparison to examine two food distribution networks, one based in a rural and the other in an urban region of Pennsylvania. Both food distribution networks focus on conventional wholesale produce distributors who serve as the link between local producers and local buyers. Stevenson and Pirog derived their value chain model in part from case studies of farmer cooperatives and food distributors that have actively designed their operations to incorporate alternative agrifood movement goals and values. In contrast, the cases we examine focus on food distribution networks that have developed to meet local produce needs, but lack explicit origins in the alternative agrifood movement. By comparing these networks to value chains, we are able to identify challenges that are specific to food systems that are in a transitional state and are moving toward regionalization by combining local resources with differentiated products. Findings from this research highlight the difficulties that conventional distributors face both in integrating themselves into successful local food system development and in pursuing equity outcomes for both producers and consumers. The distributors in these case studies faced challenges in coordinating local food distribution networks in ways that, through a comparison with the value chain framework, stand out as specific to transitional food systems. In the following sections, we will lay out the elements of successful value chain management, and then use these elements to identify and explore these challenges.

Value Chain Framework

Localized food systems that reduce the number of intermediaries and spatial distance between producers and consumers are often described as strategies to promote rural development; they achieve this by redistributing value along the food supply chain[6,7]. In contrast to the 'conventional price squeeze,' these food systems offer opportunities for local development through entrepreneurship that focuses on creating specialty and value-added products and using innovative marketing techniques to re-connect producers and consumers[8].

Value chains can play a role in local food system development that benefits a wide range of producers and consumers. Stevenson and Pirog describe the value chain framework as: '... strategic alliances between midsize independent (often cooperative) food production, processing and distribution or retail enterprises that seek to create and retain more value on the front (farmer or rancher) end of the chain, and effectively operate at regional levels' (p. 120)[3].

This framework incorporates traditional concerns about food supply chain economic performance, which may correspond to the structure, organization and practices of the chain as well as its geographic locus and product focus[9]. It also reflects elements that have been explored in studies of other sectors, such as the garment industry, which have examined how personal relations and trust across supply chain partners foster shared governance and the ability to solve problems of mutual concern[10,11]. Thus, Stevenson and Pirog's framework emphasizes a value chain structure that integrates various conventional supply chain management techniques with more explicitly 'alternative' goals of creating equitable social and economic benefits for all chain participants.

The key elements that distinguish value chains from traditional supply chains and which support these alternative goals include: differentiating value-added products, committing to the welfare of all participants, creating strategic partnerships and the role of trust and shared governance[3]. We briefly describe these features below, which then provide an analytical framework for evaluating the organizational structure and equity implications of food distribution networks that combine conventional infrastructure and local produce.

Differentiation and value-added

'Differentiation' adds value to produce through strategies such as processing or labeling. Such differentiation often brings price premiums that can promote economic viability for producers[12]. Based on consumer demand and preference, various product and process-based characteristics now differentiate food products. Such characteristics address consumers' health concerns (e.g. hormone and antibiotic-free, as for meat and dairy), environmental concerns (e.g. organic or sustainably grown), or growing interest in the geographic provenance of food[3]. Producers who can take advantage of the special skills or qualifications for creating these differentiated products may have a competitive advantage in the marketplace.

Product differentiation and adding value is in large part reliant on consumer perceptions. In many cases, regional provenance is recognized as providing social, economic, environmental and health benefits for producers and consumers[13]. Quality is therefore increasingly associated in consumers' minds with local provenance, despite the fact that many researchers have outlined ways that promoting 'local' food and agriculture does not necessarily ensure positive social or environmental outcomes[14–18]. However, the popularity of the local food movement has helped to bestow value on labels that indicate product origin, which can be used to differentiate products. One area of differentiation is a label or brand that helps to tell the 'farm story' of the product[3]. In addition to adding value, a farm-based brand can help even out power imbalances along the value chain by giving producers more control over the product. Labels provide information about the producer and a recognizable brand that creates consumer trust, and are also an important part of communicating the various quality attributes mentioned above.

Committing to the welfare of all participants

The next important aspect in value chain development concerns the redistribution of the economic value created through differentiation. Value chain participants must be committed to 'the welfare of all participants in the value chain,' which includes the fair distribution of profits. Stevenson and Pirog describe pricing mechanisms that include '... formulas for adequate margins above production costs and adequate returns on investment,' as well as ''target- or cost-based' pricing' (p. 131)[3]. In calculating their costs, value chain participants also take into account the need to provide a living wage and benefits to employees.

While these strategies are economic in nature, their ultimate goal is to use economic viability as a means to ensure the social well-being of all participants along the supply chain. Because they are based on the concept that all participants deserve to be fairly rewarded based on their costs and reasonable return on investment, value chains tend to eschew the competitive pricing and bidding common in most industries.

Creating partnerships

This philosophy of fair distribution of value shifts the nature of business relationships between supply chain participants. Stevenson and Pirog[3] contrast value chains with two other business models that are most common in the traditional produce industry, specifically arms-length and vertical integration. One of the key differences between these models and value chains is that relationships are constructed as strategic alliances in the value chain model. Treating producers and food processors as partners represents an important conceptual difference between value chains and the conventional food system, especially since most food system actors '... are accustomed to operating as cheap input suppliers in adversarial and/or arm's-length market relationships' (p. 129)[3]. Because value chains are based on cooperation along the vertical structure of the supply chain, they can increase overall efficiency and adaptability; in comparison, vertically integrated chains are not as flexible in the marketplace, while traditional adversarial relationships can impede the functioning of the chain as a unit.

Increased efficiency and adaptability are accomplished, in part, through active coordination of the supply chain, including sharing information between participants and joint problem solving. Such information sharing can be challenging for actors in supply chains who are accustomed to adversarial, competitive relationships. Treating each other as partners and recognizing mutual interdependence help to enhance trust so that sensitive information can be used to coordinate the supply chain[3].

The role of trust and shared governance

This shift from arms-length relationships to partnerships often necessitates a shift in governance, which raises issues of power and perceived justice. The Agriculture of the Middle task force seeks to empower mid-size producers, who may be too large to rely solely on direct markets, but too small to fare well in commodity markets. The value chain model is seen as one promising way to shift the balance of power in a food system that tends to disadvantage mid-size producers[3,19]. However, Stevenson and Pirog balance the ideas of partnerships and empowerment with realistic views of supply chain operations. They recognize that most supply chains will most likely not distribute power equally, but may still retain elements of procedural justice, which is, 'the perceived fairness of the powerful party's process for managing the relationship' (p. 128)[3]. Procedural justice may also encompass, '... trust in the fairness, stability, and predictability of the procedures and agreements among strategic partners; and that policies are consistent and stable over time, and do not change with new management or personnel' (p. 124–125)[3]. Thus, Stevenson and Pirog suggest that trust between organizations becomes more important than personal trust, which is the hallmark of direct marketing. Personal trust could prove to be an unstable resource, if and when key individuals leave organizations[10]. Procedural mechanisms for establishing inter-organizational trust include minority ownership, quality assurance systems, third party certification and long-term agreements. Often agreements may be informal, and therefore rely more on a sense of mutual obligation and interdependence than on formal legal grounds. These types of mechanisms embed trust in the procedural management of the supply chain.

Methods

Qualitative case study methods were used to develop two case accounts examining how actors from the conventional

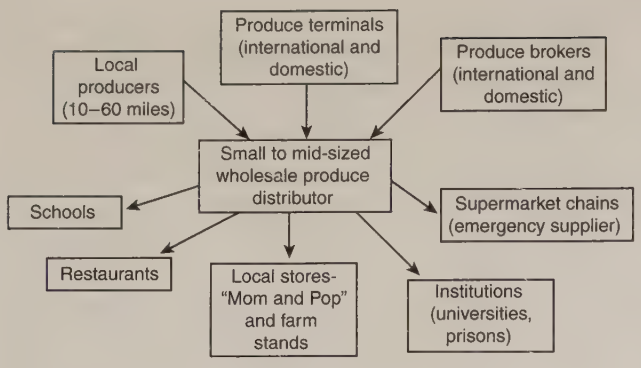
Produce terminals (international and domestic)
Local producers (10–60 miles)
Produce brokers (international and domestic)
Small to mid-sized wholesale produce distributor
Schools
Supermarket chains (emergency supplier)
Restaurants
Local stores- "Mom and Pop" and farm stands
Institutions (universities, prisons)

Figure 1. Composite food distribution network centered on a conventional distributor.

food system, specifically wholesale produce distributors, manage the supply chain between local producers and buyers. The two cases were originally identified through a study of Farm-to-School (FTS) programs in Pennsylvania, USA[20]. A mail survey of public school district food service directors permitted identification of districts procuring local foods for their food services. Case studies of FTS initiatives were conducted in eight school districts. Although FTS programs are often assumed to involve direct marketing by farmers to school food services[21], our district case studies found that some districts instead purchase their local produce through wholesale produce distributors, a situation confirmed in other research on FTS programs in the U.S. Northeast and Midwest[22]. This paper focuses on two such distributors who purchased some produce directly from local producers, and also purchased nationally and internationally through conventional channels such as produce terminals and brokers. These two distributors provided points of entry for the investigation of two food networks that connect local producers and local buyers by way of one intermediary (see Fig. 1 for a schematic). Our approach emphasized multiple participants' perceptions of and interactions within the network, instead of focusing on the distributor's role alone. Based on network participants' place perceptions and 2000 census population data, we characterize one network as 'rural' and the other as 'urban.'

A snowball sampling method was used wherein the two wholesale distributors served as key informants and provided the names of others (e.g. producers and buyers) in the network. We asked the distributor for the names of those producers and buyers whom he considered to be 'local'; as a result, participants in both cases were located within 10 and 60 miles of the distributors. In the urban case, the initial interview with the distributor revealed that an outside organization had been very active in facilitating the relationships between the distributor and producers, and therefore the scope of the study was expanded to include this non-profit actor. We interviewed three producers in the rural food distribution network and two in the urban; one distributor for each case; and three local buyers in each case, for a total of 14 participants for the entire study (see Table 1). Two interviews were conducted with each distributor; all other study participants were interviewed once.

Table 1. Study participants in the urban and the rural food distribution networks.

Rural network	Urban network
Three producers	**Two producers**
Average size: 225 acres	1–2 hydroponic greenhouses
Average sales to distributor: 1%	Average sales to distributor: 40%
Distributor	**Distributor**
Gross sales 2007: $5–9 million	Gross sales 2007: $10–14 million
Buyers	**Buyers**
1 School	1 School
1 Restaurant	2 Restaurants
1 Farm stand	

Both distributors in this research have been in the wholesale produce business for at least 10 years. Neither business was established in order to take advantage of the recent intensified enthusiasm for local foods, although each has subsequently responded to that opportunity. Therefore both businesses can be considered part of a pre-existing food system infrastructure that is now playing some role in the transition toward a regionally based food system[2]. In addition, each of the distributor's business is independently owned and operated, which sets them apart from the corporate-dominated industry.

Structurally, the rural distributor is slightly smaller in terms of gross sales than the urban distributor (see Table 1). The producers in the rural food distribution network are larger on average than those in the urban food distribution network. Notable buyer characteristics include the large size and tourist attraction status of the rural network restaurant, and that both urban network restaurants serve high-end markets. The influence of context on how these conventional infrastructure actors handle local produce, and the relationships that arise from its procurement and distribution, are considered in the next section.

Applying the Value Chain Framework

In the following sections, we compare the four aspects of successful value chain organization to the two case studies of food distribution networks. The style and emphasis of each area's local food movement, as reported by case study participants, provide important context for how local produce is differentiated. The approach to differentiation as 'local' has implications for how profits are distributed, the character of business relationships that distributors form with local producers and local buyers and the governance mechanisms coordinating the supply chain. As we describe how these two food distribution networks correspond to (and depart from) the value chain framework, we highlight organizational and equity issues that deserve consideration

Table 2. Value chain framework elements in the rural and urban food distribution networks.

Feature	Rural network	Urban network
Differentiation and value-added	**Producers:** Do not label produce as 'local', although perceive benefit through other marketing channels	**Producers:** Use farm-name labels, but lack control over produce handling
	Distributor: Perceives low demand for 'local' produce	**Distributor:** Actively markets 'local' to create competitive advantage
	Buyers: Prefer farm stands and produce auctions for 'local' produce	**Buyers:** Promote 'local' as part of business strategy
Committing to welfare of all participants	**Producers:** Sell surplus to distributor with market-based pricing	**Producers:** Set own prices according to costs
	Distributor: Empathizes with farmers, but prioritizes low prices for buyers	**Distributor:** Uses two-tier pricing (commodities and specialty items)
	Buyers: Demonstrate little demand for premium priced 'local' produce from distributor	**Buyers:** Restaurants often pay more for 'local' products, but schools prioritize price
Creating partnerships	**Producers:** Sell to distributor, but as one minor market relationship among others	**Producers:** Vary between working with distributor to coordinate supply and not sharing information
	Distributor: Recognizes inter-generational social relationships, but does not favor local producers	**Distributor:** Frustrated at inability to find local producers who will commit to selling only wholesale
	Buyer: Partner with distributor, based on customer service benefits	**Buyer:** Partner with distributor; exhibit joint problem-solving
Role of trust and shared governance	**Producers:** See distributor as fair, based on personal trust and reference to commodity markets	**Producers:** Vary between high and low trust in distributors' operations; perceive little recourse to address complaints
	Distributor: Emphasizes personal trust, based on intergenerational social history and 'word of mouth'; little formally shared governance	**Distributor:** Unsuccessfully sought contractual agreements to improve reliability of 'local' supply; exploring competitive bidding
	Buyers: Display personal trust, based on shared history and overlapping social and business ties	**Buyers:** Actively facilitated coordination with distributor and local producers

in charting pathways for transitioning toward a more sustainable regional food system (see Table 2 for an overview of these findings).

Differentiation and value-added

The ability of producers and distributors to extract value from local produce depends on consumers' willingness to recognize and pay a premium for that extra value. In this study, that willingness appears to rely in part on the nature of the local food movement that prevails in each area. In the rural case, the distributor, farm stand owner and restaurant owner reported that their customers' association of local produce with their rural and agricultural heritage fostered the idea that farm stands and produce auctions were more appropriate sources of such produce than a produce distribution company. For example, the farm stand owner had a pre-season agreement with two local farmers to provide produce, in addition to the sweet corn that he and his family grew themselves. The restaurant owner found it more economical to buy produce by the ton or half ton from the local produce auction, which he also felt supports the local farm economy. For these buyers, freshness and volume made these sources more appealing than buying through the distributor. The farm stand owner noted, 'When my local sources become available, that immediately takes precedence over what would be handled through a distributor.'

The fact that his buyers also sourced local produce from other establishments may help to explain why the distributor did not perceive much consumer demand for local produce, and therefore why he did not consider local produce a differentiated product meriting much of a price premium. This was partially reflected in his opinion of labels, such as PA Preferred, which is run by the Pennsylvania Department of Agriculture to help identify and promote Pennsylvania produce. The distributor said that he found such promotional efforts too expensive and not necessarily beneficial for producers: 'I'm not a big advertising person. So, it's an expense for them. And I don't know if it's justified by the return, because there's no guarantee that they're going to get an extra quarter or dollar a package just because it has a PA label sticker on the box.' In the rural network, the producers and buyers used such place of origin labels only minimally. One producer did not use any labels, but believed that his ability to sell directly to a local supermarket chain had improved because of the demand for local produce. The farm stand owner did not highlight PA Preferred labels, but relied instead on home-made signs saying, 'Our Own,' or 'Raised Here.' Although the distributor did not receive much demand for local produce over the summer, the farm stand owner reported that the customers that come to his farm stand, '... wouldn't look at something that was shipped in, actually, I couldn't sell certain items-like corn, if I had my own sitting there

and something that was shipped, I don't think I could sell the others!' These divergent perspectives on the presence of demand for specifically 'local' produce suggests that while there may be demand in this area, it circumvents traditional suppliers such as the distributor in favor of other sources.

In comparison, in the urban context the distributor, producers and restaurant chefs reported that a well-articulated local food movement had gained momentum over the past 5 years. This movement corresponds to a larger national trend and is manifested by deliberate and sometimes coordinated efforts to promote urban agriculture, farmers' markets and sustainable agriculture[13]. Here, the presence of an active local food movement has stimulated consumer demand for local products. Urban network participants were therefore very aware that local food offered value as part of a successful business strategy. The demand for local produce and the strong presence of a local food movement encouraged product differentiation based on provenance, where the quality of being 'local' is considered a clear added value. Being able to identify and label local food is necessary for it to contribute to a business strategy. All participants in the urban network had done this. Producers and buyers relied on the marketing efforts of the distributor and reported that labels such as PA Preferred or Buy Local did not carry as much weight as they would in the retail market, because the distributor actively promoted product origins by using farm names. Such promotion of named local products is part of a business strategy that helped the distributor to develop his reputation. Offering high-quality local produce allowed him to take advantage of a niche market and gave him a competitive advantage. For example, he said: '... You're always looking for a way to expand your business to be a leader, ok, you always want to be one step ahead of the game ... this product I bring in nobody else has, it's sort of like Microsoft—everybody uses Microsoft because they're the leader, because they set the bar.' The urban distributor valued his buyers' recognition of his commitment to local produce, and the chefs purchasing from him also indicated that their consumers were discerning when it came to their produce choices.

Both the distributor and the chefs in this network said that they perceived greater demand for local products than for certified organic products. In addition to addressing consumers' health concerns during food scares, promoting local produce gave these restaurants a certain cachet, based on the implied superiority of their products. One chef pointed to the positive publicity that purchasing local and having an environmental slant got them, and how it served to differentiate them from other restaurants to provide a competitive advantage, 'We're being basically grouped together with the rest that are trying to be more 'green,' so to speak, and trying to buy local, better-for-you food. And to be talked about in that capacity, and to be grouped together with restaurants that also function like that, has definitely shined a positive light on us.' Only the school district, whose limited budget made low prices a priority, did not actively seek and promote local produce, except in the context of a once-a-year celebration of local apples.

Both producers in the urban food distribution network were highly aware of the economic value of the quality of being local, and used their own specific labels identifying their operations by name. Although the value chain framework describes branding techniques such as farm-based labels to help producers maintain ownership over the product throughout the supply chain, both producers in the urban network, in contrast, reported concerns about losing control over their product once it passed to the hands of the distributor. One producer said, 'When we drop off our lettuce, it can sit on that dock for 2–3 hours before it gets put in the freezer, put in the cooler, so it could sit out there and wilt, go bad, and my name's on it. So I lose the control on that.' Both producers pointed out that because the product carries a label identifying their operation by name, and this is the information that restaurant chefs often include on their menus, the end consumer's judgment of the quality of that product affects their operation's reputation. Lack of control over product handling before its sale was a frustrating aspect of these producers' relationship with the distributor, indicating some lack of confidence in the distributor's operation. One producer said that he saw no way to address this issue, because his product was out of his hands once it reached the distributor. Here, despite having ownership over his label, the producer did not feel empowered, nor did he feel that he had the right to express his opinion about how the distributor handled his product. This suggests that differentiation alone may not ensure a sense of partnership among supply chain participants. The development and maintenance of collaborative relationships between participants in transitional food distribution networks, such as these, can face obstacles.

Committing to the welfare of all participants

Whether or not local produce can generate a premium affects the type of returns producers get for their product. In these cases, both distributors struggled between their recognition that producers need to receive fair prices to survive and their own need to offer low prices to their buyers to stay competitive. Because of lower demand for local produce through the distributor's business in the rural food distribution network, offering fair prices to local producers was often more challenging for the rural distributor than for the urban. The rural distributor often talked about giving producers fair prices in order to maintain these relationships and, perhaps partly because of his own farming background, appeared to have a lot of empathy for producers. For example, he talked about how he and the producers purchased from shared economic goals, the reciprocity of the relationship and his attempts at maintaining fairness as follows:

> So you know, I try not to take advantage of them. They need to make a profit, I need to make a profit, that's why we're both here; lot of people want to gouge you, and I try not to

> do that. I try to make a fair profit to cover my expenses, give as much back as possible. Because if you don't give any back this year, they won't be there next year.

These comments convey the distributor's recognition that producers' economic returns are related to their operation's viability and economic sustainability. Although he talked about fair prices, the distributor said that he was only interested in local products when producers' prices were comparable to the same non-local product: 'If they're just getting started and have very little volume, if they can get a premium price—call me when you have a surplus, then I can deal with it.' The 'premium price' that the distributor was referring to here has to do with the timing of the product, since producers can receive higher prices when there is scarcity in the market for a particular product. It was not a higher price based on the quality of being a local producer or based on a producer's costs, but rather on market conditions. Fairness was therefore not built into the price of local items, despite the distributor's recognition of the need to pay farmers good prices to help them stay in business. The fact that he only dealt with local farmers when they could meet his needs on price and volume limited him to buying surplus produce when the market was flooded and prices were low.

For the urban distributor, the presence of high-end buyers who were willing to pay more for local produce allowed him to be more flexible with pricing. The distributor balanced between determining prices for more commodified items according to the market and allowing producers for specialty products to set their own prices based on cost. In this way, he treated some producers as arms-length suppliers of generic products and others as strategic partners. For example, with a commodity like corn, the distributor said, 'We try to go off the market. If corn gets wiped out, they're going to want more money for it, and that's just fair; if there's an abundance of corn, I expect to be treated fairly.' However, with specialty items such as one of the local producer's micro-greens, he said, '[That Producer] is more stable pricing.' Both of the local producers included in the urban case study sold specialty products that they were able to price based on their costs; one producer clearly stated that he was able to do so because the 'local value' of his product meant that it was not a 'real commodity.'

The fact that the urban distributor's buyers were willing to pay more for local products helped to support this pricing system, although the distributor also said that there was a limit to how much more buyers would pay for local produce. When it came to prices, the urban distributor was acutely aware of his responsibility toward his buyers and respected the fact that most of his clients needed to re-sell the produce. His awareness of his client's financial limits was especially true for the school district, where he said, 'Cause here's the thing, if I can get Florida tomatoes for 60 cents a pound in the fall, and the local guy wants a dollar a pound, how am I supposed to justify to [the Food Service Purchaser] that I'm doing my job also, as her buyer, and selling her the best price possible?' Here he clearly prioritized the buyers' needs, although working as well with higher end restaurants gave him some freedom to support producers when they sought higher prices.

Creating partnerships

Consumer demand and the value attributions for local produce also corresponded to the types of business relationships that developed between distributors and local producers and buyers. In both the rural and urban local food distribution networks, the relationships between these distributors and their *buyers* tended to be more characteristic of partnerships according to the value chain model than were their relationships with local *producers*. For the rural distributor, his relationships with both buyers and producers were characterized by an intergenerational social history; however, commitment to customer service led him to prioritize buyer needs over his established relationships with producers. In his relationships with producers, he alternated between acknowledging the needs and goals of the producers that he worked with, which made the producers sound like strategic partners, and reverting to standard, arms-length relationships, where the producers sounded more like generic suppliers. Despite his intentions to give producers what he called a 'fair shake,' ultimately the distributor also needed to seek out low-priced items in order for his business to remain competitive. When the distributor transferred the responsibility for his relationship with producers onto the demands of consumers, it made these long-term relationships sound much more tenuous. For example he said:

> I might deal with them this year and not next year, it's just depending on the market, it's no bad feelings between the farmer, no favor between me and the farmer, but maybe they just don't have what I need and that's how you need it. Have it this year, might not have it next year.

There was little sense that the distributor would work with a producer and the consumer to coordinate supply and demand, or that they would work together to address problems. Consumer demands took precedence over pre-established relationships with local producers and if the distributor could better meet these demands by sourcing a product from a non-local source, either because of price or quality considerations, he did. As mentioned earlier, this often restricted the distributor's local purchases to times when there were surpluses and low prices on the market. The distributor unwittingly contributed to competition between local and international producers by comparing prices and quality between these two sources and not privileging one over the other based on mutual interdependence, as described in the value chain model. This tension points to the inherent difficulties of creating a sense of partnership all along the supply chain, especially because of the often diverging economic needs of producers and consumers.

In the urban food distribution network, the distributor combined arms-length relationships and strategic partnerships depending on his buyer's demands. Most of the produce that he sourced for the school district required arms-length relationships with producers and brokers that grew and handled commodified, standardized produce. However, with buyers who demanded local produce, such as the chefs from high-end restaurants, the distributor took a more active role in sourcing local produce and attempting to foster partnerships with local producers. Still, when working with his buyers, this distributor also prioritized consumer demands above local produce purchasing, and often described his relationships with buyers in ways that resonated with the value chain framework. For example, when lettuce prices skyrocketed, the Food Service Purchaser for the school district said that she had daily communication with the distributor, who helped her plan how much to buy, when to buy it and switched vendors to keep prices down. On her end, the Food Service Purchaser worked with schools to reorganize their menus and replace or reduce the amount of lettuce they were using. The distributor and the buyer exhibited joint problem-solving efforts to address the purchaser's financial constraints; however, unlike in the value chain model, this was done without any type of coordination on the producer's end, and was achieved by switching vendors, not by working through the problem on the supply end as well as on the purchasing end.

When dealing with local chefs, the distributor actively sought more strategic relationships with local producers; however, the high demand for local produce in this area put pressure on the distributor, which in turn shaped his relationships with local producers. Because purchasing and promoting local food was an integral part of the distributor's business strategy, he was interested in finding ways of securing consistent, reliable relationships with local producers in order to coordinate the supply chain dynamics between production and consumption. However, the presence of a local food movement and high consumer demand provided economic opportunities for producers through direct marketing outlets such as farmers' markets and selling direct wholesale to supermarket chains. This high profit margin retail market for producers created tension in the relationship between the distributor and local producers and impeded partnership development. It also motivated the distributor to work with a non-profit organization to find local producers willing to sell exclusively to a wholesale market. While many producers would have liked to sell only their surplus to the distributor, the distributor needed a steadier supply of local produce to meet his buyers' demand; however, he could not compete with the higher prices offered in the direct retail and direct wholesale markets. The distributor wanted consistent relationships that may resemble partnerships under the value chain model, while the producers appeared to prefer remaining more like suppliers and dealing with the distributor only when it was beneficial for them. New opportunities in local markets shifted power toward the producers, who treated the distributor with the type of inconsistency that producers usually face in conventional supply chain relationships. For the producers that chose to sell exclusively wholesale to the distributor, their perceptions of their relationships differed. The less experienced grower felt that he worked with the distributor to coordinate supply and demand, showing a sense of shared partnership, while the other producer preferred remaining autonomous in terms of his product selection and promotion.

The role of trust and shared governance

Relationships that distributors formed with local producers and buyers in turn provided the context for the expression of trust and specific governance mechanisms coordinating the supply chain. While the rural distributor relied on a mixture of personal and market-based mechanisms to manage his relationships with local producers, the urban distributor struggled to find appropriate mechanisms to maintain consistent relationships with local producers. The rural distributor had intergenerational social ties with the three local producers, which fostered personal trust. While this may have led to perceived fairness, it did not necessarily create inter-organizational trust through shared governance and procedural mechanisms, as described in the value chain framework. The distributor acknowledged the role of personal trust in maintaining his relationships with local producers and gave a compelling example of how producers would deliver their products to him before they had settled on a price: 'Nine times out of ten, [the Producer] will send me stuff with no price on it, and I price it after I sell it. I've done that for years, I guess they just trust me.' The producers' faith that the distributor would be honest in pricing their products was based in part on personal trust and in part on the distributor's upfront reliance on commodity markets to determine prices. When asked how he decided which producers to buy from, the rural distributor responded, '... as far as buying from the people I deal with, they're just reputable people, they're honest and reputable people.' Personal characteristics such as honesty formed a basis of trust for the distributor, and this trust appeared to be reciprocal, although backed by market mechanisms. For both buyers and producers in the rural network, the fact that they all moved in similar social circles may have helped to maintain these relationships, and may have served as a check on their business relationships. Although they did not enter into agreements that would have legally enforceable consequences if trust were broken, the distributor's reliance on 'word of mouth' and social connections with producers and buyers may have provided some incentive to remain honest, reliable and responsive to any potential problems. Despite little evidence of inter-organizational trust, personal trust here may have served as a governance mechanism[23,24].

Personal trust between producers and the distributor and perceived fairness notwithstanding, the rural network did

not share governance in a way that might foster partnerships and ensure equity along the supply chain. No procedures were in place to coordinate the chain, and the distributor said that he told producers, 'I'll tell you guys, if you don't have it, you don't have it, but it's just a phone call away to find it someplace else.' One of the local producers supported this point, saying independently of the distributor, 'Oh, if he can buy a similar product for cheaper, you won't see him. You won't see him. He's a money man.' Beyond the absence of explicit agreements or other mechanisms, these comments reveal little mutual interdependence between the producers and distributor. This distributor's readiness to source products from non-local sources to ensure his supply suggests clear limits to an ideal of shared, collaborative interests.

In contrast, the urban distributor struggled to determine what types of supply chain mechanisms he might utilize to bring a degree of consistency to his relationships with local producers. Although he expressed interest in our first interview in working with the non-profit organization to establish contracts with local producers, the producers expressed little interest in committing to pre-season contracts, which they believed would be too constraining. By our second interview, the distributor had shifted away from the idea of contracts, while still expressing frustration with producers' desire to switch in and out of different types of markets. For example, he said, 'It's not an agreement, you just hope—look, if I'm buying off of them, I want to be kept in the loop, I want my product, I don't want to hear, well, it's the [County] farm show, I'm going to take all my stuff retail and I can't get you this this week ... I'm going to buy it, I want it.' Here, the distributor reflected on the challenge of establishing a relationship of commitment between partners, with the reliable outcome that a producer would give this relationship precedence over other possible markets. He did not specifically see this relationship working yet through contracts, and he did not mention any other procedural mechanism that might help to formalize and consolidate his relationships with producers. However, he mentioned that he had recently decided to buy from a produce auction in a nearby rural county to ensure being able to obtain the volume of local items at the prices he needed to maintain his business. He remained committed to buying local produce, but his switch to an outlet relying on competitive bidding to establish prices can be viewed as a move away from a value chain model and toward the replication of traditional arms-length supply chain relationships with producers. Here again, the producers that did maintain a relationship with the distributor diverged in their perceptions of these relationships, with the less experienced grower expressing high levels of trust and the other remaining unsatisfied with how the distributor handled his product, but feeling that he did not have recourse to address the issue. The buyers in this network, on the other hand, saw themselves as active facilitators in coordinating the local food supply chain, as evidenced by one of the chef's role in connecting the distributor with local producers.

Discussion and Conclusions

We have used the value chain framework as a lens for examining the organizational and equity implications of supply chain dynamics that emerge as conventional food distributors play a greater part in local food markets. In this study, we found that transitional food systems that pivot on actors accustomed to working in the traditional produce industry can encounter challenges surrounding the generation and distribution of economic value, as well as coordinating supply and demand. These challenges arise, in part, because consumers and producers may not identify conventional produce distributors as a source or destination for local products. In the rural network, for example, buyers preferred sources other than the distributor for local produce, while in the urban network, specialty producers could earn more by selling, not to the distributor, but to other buyers. Such situations can undermine the conditions for developing a sense of partnership between local producers and distributors, as occurred in this study even though differentiation, local branding and heightened consumer demand were all present. Shortfalls in partnership development may also derive from distributors' prioritization of customer service over a commitment to local growers. Distributors often felt caught between offering fair prices to producers and giving low prices to their buyers, with the latter being the most crucial for distributors' economic viability.

This study provides food for thought for policy-makers and practitioners who view conventional infrastructure as a potential vehicle for 'scaling-up' local food systems, thereby contributing to both rural development through expanded markets for producers as well as accessibility to local produce for consumers[25]. Both the networks studied here faced barriers to meeting the dual goals of making local produce more widely accessible while also redistributing value along the supply chain to all participants. Although the value was redistributed toward specialty producers in the urban network, these small-scale producers and the limited nature of the outlets for their products (which included high-end restaurants, but excluded larger buyers, such as the school district), may mean that this type of food distribution network will have a limited contribution toward scaling up the local food system, and in turn influencing the local economy. On the other hand, in the rural network, the weak differentiation of local produce posed a barrier to generating economic value. This restricted the ability of this food distribution network to contribute to rural development by bolstering producers' economic viability.

Another barrier for these two local food distribution networks seemed to be the common perception in both cases that local produce would be less expensive than imported produce because of shorter shipping distances. For example, when asked who may or may not benefit from a more localized food system, the chef from one of the urban restaurants responded, 'But I mean, the farmers

would benefit, the consumers would benefit, the middleman, the places that are buying the stuff will benefit. You know, it's cheaper to get the product there, and often times cheaper than buying stuff from far away.' Although this claim may be true during the height of the summer growing season, its general validity is questionable, particularly if consumers are not willing to pay enough more for local produce so as to improve the economic outcomes of local producers. Producers, however, understood that local produce is not necessarily cheaper just because it has been shipped shorter distances. In fact, one producer in the urban network said, as a hypothetical customer for his own product, 'I wouldn't pay what they're paying for that lettuce—it's outrageous!' This statement highlights the challenge that local food distribution networks, based on a value chain model, face in providing local produce to a wider consumer base while still generating enough economic value to support all chain participants.

These findings suggest that promoting rural development by moving local produce through the conventional food system infrastructure will require additional strategies to generate and redistribute value. Addressing the broader infrastructural needs of local and regional food systems could foster economic development and meet the divergent needs of both producers and consumers. For example, locally owned processors could create economic opportunities for producers to add value to local produce, as well as increase the ability of local buyers to purchase it. This is especially true for institutional buyers such as schools, hospitals or prisons that often have limited on-site processing capabilities and increasingly rely on pre-processed items[26]. Other research indicates that expanding the networks that develop around producers to include processing and distribution facilities (i.e., agrifood clusters) can have a positive impact on the overall economic performance of such networks, which in turn has important spillover effects on the local economy[27]. In addition, supporting the development of processors that are independently owned and operated provides opportunities for entrepreneurship and increased rural employment[27,28].

Another strategy to consider is promoting more shared ownership models. While the value chain framework identifies a role for shared ownership in the form of minority ownership (e.g., where the downstream actor has a stake in the suppliers' business), Brasier et al.[27] provide the example of a producer cooperative that expanded to establish a processing facility. Here producers have a stake in the ownership of the facility, as do community members who choose to invest in the business, both to support local farmers and to protect the area's farmland. Welsh's research further supports shared ownership models, such as producer cooperatives; he cites several studies that analyze the impacts of state policies that protect farmers' collective bargaining rights[28]. These studies showed that, 'membership in the marketing cooperative enabled growers to have more input into the terms and conditions of their contracts with apple processors' (p. 26), in addition to achieving higher prices[28]. Some new generation cooperatives, such as Organic Valley, the largest organic farmer-owned cooperative in North America, offer evidence that a formal cooperative model can provide a platform for creative deployment of value chain elements that yield business success, social innovation and equitable outcomes[29]. But even though they may emerge as a response to increased market demand, shared ownership models may not readily mesh with the business histories and norms of conventional food distributors, as studied in this research.

Based on comparisons with the value chain framework, our research suggests that food distribution networks relying on conventional infrastructure to promote and provide local produce may face challenges in meeting both producers' and consumers' needs. Several avenues for future research on the transition to more local and regional food systems can be highlighted as a result. As conventional agrifood enterprises and institutions step in to buy and sell local and regional foods, it will be important to evaluate the longer term organizational and equity implications of this practice. More extended organizational studies can evaluate whether moving local food through conventional food system infrastructure is a necessary, but ephemeral practice that serves food system transition or whether it is a more transformative and ongoing practice for conventional food system businesses. In other words, do conventional food distributors simply play a short-term role conveying local food in a given market that still lacks sufficient dedicated infrastructure? Do the perceived drawbacks of these arrangements actually create opportunities for new businesses more explicitly embracing value chain equity considerations to emerge? Or does the very engagement of conventional food businesses with local and regional food markets gradually transform the operation and orientation of such businesses so that they make sustained and important contributions to more local and regional systems? By identifying and evaluating diverse distribution models for local and regional foods, we can better recognize and support the changes in institutions, enterprises and individuals that offer promising pathways to a more sustainable food system.

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Efficiency of an agrosystem designed for family farming in the pre-Amazon region

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Abstract

In the humid tropics, the continuous use of the same area reduces nutrient availability and increases the incidence of weeds. To circumvent these obstacles, farmers practice itinerant agriculture associated with slashing and burning with negative effects on the local and global environment. In search for a suitable system for humid tropical agriculture, the objective of this study was to investigate the performance of no-till alley cropping in conjunction with the use of annual legume crops grown during the off-season. The experiment was implemented in a one-hectare alley cropping system in which the leguminous tree clitoria (*Clitoria fairchildiana* R.A. Howard) was used. The experimental design consisted of randomized blocks with four replications of the following treatments: Stylosanthis (*Stylosanthis capitata*), showey rattlebox (*Crotalaria spectabilis*), sunn hemp (*Crotalaria juncea*), jack bean (*Canavalia ensiformis*) and a control with clitoria alone, without an annual legume. In January 2007 and 2008, maize was planted in each alley. One hundred and twenty days after annual legumes were sown, the total biomass was recorded. Weed incidence was assessed 35 days after maize planting. Analyses of the C, N, P, K, Ca and Mg contents of the legumes were carried out. To assess soil organic matter (SOM), composite soil samples from the surface 0–5 cm were collected from experimental plots. Two adjacent areas were also sampled for comparison: a 10-year-old secondary forest and an area of conventional tillage. The SOM was fractionated using a densitometric and a granulometric method. Conventional systems reduce the silt and free light organic matter fractions more than no till. The use of annual legumes changes the composition of the weed community, replacing the more aggressive types with those less competitive. The use of showy rattlebox (*C. spectabilis*) may be an effective strategy for reducing weed density in the long-season crop. Furthermore, relative to the use of leguminous trees alone, higher yields of maize can be obtained with the use of showy rattlebox (*C. spectabilis*) and sunn hemp (*C. juncea*) without the application of additional N.

Key words: leguminous, weeds, soil organic matter, maize productivity

Introduction

In the humid tropics, high temperatures and rainfall combined with soils derived from clastic sedimentary rocks result in unfavorable conditions for sustainable agrosystems. In particular, continuous use of the same area reduces the nutrient availability and may result in an increase of weed pressure[1,2]. To circumvent these obstacles, farmers in the pre-Amazon region practice itinerant agriculture associated with the slashing and burning of natural vegetation that grows during the fallow periods between slash and burn events. Under this system, the burnt ash increases nutrient availability, while the shifting of cultivation prevents the accumulation of weed seed banks, which become inexorable if successive cultivation is used[3]. Approximately 80,000 ha are slashed and burnt every year in the pre-Amazon region[4].

Unfortunately, with the growing number of farmers and the consequent reduction in fallow periods, this system no longer offers economic and social benefits to offset its negative effects on the local and global environment. In the local environment, the demand for farmable area leads to successive fires between ever-decreasing fallow periods, eliminating the species most susceptible to fire and allowing the most resistant species to predominate. This cycle reduces biodiversity and impoverishes ecosystems[5]. At the

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global scale, biomass burning contributes up to 1.1 Pg of carbon emissions each year, because approximately 95% of the total carbon of the biomass is released by burning. In Brazil (one of the five largest emitter countries), an estimated 70% of total CO_2 emissions is derived from uncontrolled burning of forests which emits approximately 69 tons of CO_2 for each hectare burned[6]. Thus, replacing the slash and burn system in the pre-Amazon region is justified first by the strong need to increase agricultural productivity and second by the need to reduce the environmental impact of burning tropical rainforests.

Besides the traditional focus on production, agricultural producers must also balance conflicting demands involving social, political, economic, technological and environmental issues[7]. Therefore, it is apparent that a farming system is needed, which does not rely on the application of fertilizers, which has a low cost, is consistent with the socio-economic and technological practices of the farmers and can sustain production and maintain soil fertility[8]. Several authors have recommended no-till farming of leguminous trees planted in alleys as an alternative to slash and burn methods in the humid tropics. Desirable characteristics of such a system include its ability to recycle nutrients[9], to improve soil fertility indicators[10] and to reduce weed incidence when combined with the use of annual legumes[3]. In addition, the high capacity of such a system to produce plant biomass makes it a viable alternative for increasing soil carbon stocks and reducing greenhouse gases[11].

If an agrosystem is to become established for use in humid tropical conditions, it must not only be environmentally appropriate but also attractive to farmers for its environmental and agricultural functions, such as reducing the incidence and aggressiveness of weeds, producing a sufficient quantity of residues for soil coverage and increasing the availability of soil nutrients and organic carbon through recycling[12]. In the search for a suitable system for humid tropical agriculture, the objective of this study was to investigate the performance of no-till alley cropping in conjunction with the use of annual legume crops grown during the off-season. Specifically, we sought to assess the ability of the system to increase the fractions of soil organic matter (SOM), suppress weeds that produce seeds at the end of the rainy season and sustain maize productivity in a dystrophic Plinthosol in the pre-Amazon region.

Materials and Methods

The experiment was conducted between 2006 and 2008, encompassing two annual crop harvests in north-central Maranhão state (3°36″ south latitude, 45°24″ west longitude) at an altitude of 60 m. The local soil was classified as a typical silty and loamy dystrophic Plinthosol with the following characteristics in the 0–20 cm layer: K = 2.7 $mmol_c\ dm^{-3}$; Ca = 11.0 $mmol_c\ dm^{-3}$; Mg = 7.0 $mmol_c\ dm^{-3}$; (H+Al) (a proxy for total acidity) = 56.0 $mmol_c\ dm^{-3}$. Sand = 230.0 g kg^{-1}; silt = 680.0 g kg^{-1}; clay = 90.0 g kg^{-1}. pH (H_2O) = 4.3. BS (percent base saturation) = 27.0%; P = 8.0 mg dm^{-3}; bulk density = 1.3 Mg m^{-3}. The experiment was implemented in a one-hectare alley cropping system in which the leguminous tree clitoria (*Clitoria fairchildiana* R.A. Howard) was planted at a spacing of 2.60 m × 0.50 m. During 6 years prior to the experiment, the clitoria plants were pruned at the beginning of the rainy season and its branches were applied between the rows of the annual crops of cassava, maize or rice.

The experimental design consisted of randomized blocks with five treatments and four replications. Each block consisted of two alleys with a row of *C. fairchildiana* in the center and five plots of 5.2 m × 5.0 m planted with the following treatments: *Stylosanthis capitata* (stylosanthis), *Crotalaria spectabilis* (showy rattlebox), *Crotalaria juncea* (sunn hemp), *Canavalia ensiformis* (jack bean) or a control (clitoria alone, without an annual legume).

The annual legumes were sown in continuous rows with 0.5-m spacing between plants at a rate of 7.7 g m^{-2} for the stylosanthis, showy rattlebox and sunn hemp. The jack bean was sown at a spacing of 0.50 m × 0.30 m, with three seeds per hole. Sowing took place in June 2006 and 2007, a period coinciding with the planting of off-season crops, in order to suffocate weeds that grow during this phase and that produce seeds that germinate at the same time as the main crop in the following year.

In January 2007 and 2008, at the beginning of the rainy season, four rows of maize (*Zea mays* L.), cultivar AG 5020, were planted in each alley at a spacing of 0.70 m × 0.30 m, with two seeds per hole. Maize seedlings were later thinned to five plants per linear meter. Fertilizer was applied during maize planting (20 kg ha^{-1} N, 80 kg ha^{-1} P, 60 kg ha^{-1} K and 2 kg ha^{-1} Zn), according to the most commonly used Brazilian fertilizer handbook[13]; side-dressing fertilization was not applied.

One hundred and twenty days after annual legumes were sown, their total biomass was cut and applied on the soil surface. Weed incidence was assessed 35 days after maize planting. Weed species of the family Commelinaceae were evaluated separately during the second year only. To assess weeds and legumes, samples were taken using a 50 × 50-cm iron square at four random locations per plot. Thirty days before maize planting, clitoria branches were pruned at a height of 0.50 m, weighed and evenly distributed on the soil in each plot mixed with residues of the annual leguminous crops. A sample of leaves and twigs was removed for chemical analysis. The weed, annual legume and clitoria samples were dried in a forced-air ventilation oven at 60°C until a constant weight was attained.

Analyses of the C, N, P, K, Ca and Mg contents of the legumes were carried out according to methods described in Tedesco et al.[14]. Lignin analysis was performed according to the methodology of Van Soest (1967)[15]. Phenolic compounds were analyzed using hot water and the Folin–Ciocalteu reagent. Polyphenol levels were expressed as gallic acid equivalents. The plant residue quality index (PRQI) of Tian et al.[16] was calculated using the formula $PRQI = [1 \div (a \times C/N + b \times L + c \times P)] \times 100$, where *a*, *b*

Table 1. Nutrient contents and residue quality of the leguminous species used; average of 2 years.

Parameter	Stylosanthis	Showy rattlebox	Sunn hemp	Jack bean	Clitoria
Nitrogen (g ha^{-1})	31.52 (± 2.90)	32.28 (± 3.12)	33.63 (± 3.00)	26.81 (± 2.53)	27.81 (± 2.40)
Phosphorus (g ha^{-1})	1.33 (± 0.14)	1.57 (± 1.20)	1.85 (± 0.20)	2.20 (± 0.23)	1.07 (± 0.13)
Potassium (g ha^{-1})	4.48 (± 0.47)	7.53 (± 0.61)	4.06 (± 0,32)	2.08 (± 0.19)	2.67 (± 0.32)
Calcium (g ha^{-1})	3.95 (± 0.45)	4.45 (± 0.39)	2.11 (± 0.15)	1.77 (± 0.12)	2.31 (± 0.25)
Magnesium (g ha^{-1})	0.46 (± 0.05)	0.56 (± 0.43)	0.51 (± 0.04)	0.25 (± 0.03)	0.47 (± 0.03)
C/N ratio	9.38 (± 1.10)	9.19 (± 0.86)	8.59 (± 0.64)	9.00 (± 0.86)	9.03 (± 1.20)
Lignin (%)	8.16 (± 0.89)	10.27 (± 0.96)	8.57 (± 0.69)	6.75 (± 0.52)	15.87 (± 1.70)
Polyphenols (%)	0.64 (± 0.07)	0.54 (± 0.08)	0.28 (± 0.03)	0.47 (± 0.53)	1.282 (± 0.30)
Plant residue quality index	13.27 (± 1.46)	11.92 (± 1.50)	13.50 (± 1.40)	14.78 (± 1.65)	9.76 (± 0.89)

Figures in parenthesis indicate standard deviation.

and *c* are coefficients of the content contribution of each compound, represented by the values 0.423, 0.439 and 0.138, respectively; C/N = Carbon/Nitrogen ratio and L and P = percentages of lignin and polyphenols, respectively. The residue quality measurements of each annual legume species used are shown in Table 1.

For soil analysis, samples were collected with a duty auger, from a 0 to 20 cm layer. Soil samples were analyzed for pH (0.01 M $CaCl_2$ suspension, 1 : 2.5 soil/solution, v/v), P and exchangeable K, Ca, Mg (resin) and H+Al (SMP method), according to standard methods used by the Agronomic Institute of Campinas[17]. CEC was determined as: K+Ca+Mg+H+Al. Sum of bases (SB) were calculated as: K+Ca+Mg and base saturation percentage (BSP) as SB/CEC × 100. We collected soil samples for the determination of soil bulk density with 100 cm^3 volumetric cylinders, with three replicates per plot. Each replicate was a core sample from 0 to 15 cm depth. The soil from each cylinder was dried in a lab oven at 105 °C. Bulk density (ρs) was calculated as w/v, where w is the soil weight in the dried sample and v is the core volume.

To assess SOM, soil samples were collected using an Eijkelkamp Edelman sand auger at a depth of 0–5 cm at the end of the maize cycle in the second year. In each plot, three composite samples, each made up of ten individual samples, were collected. For comparison, two adjacent areas were also sampled: a 10-year-old secondary forest and an area of conventional tillage where rice and corn had been cultivated for 2 years. Within these areas, 21 individual samples were collected using a zigzag pattern, from which four composite samples were obtained. After collection, the samples were air dried, broken up, homogenized and passed through a 2.0-mm sieve.

The SOM was fractionated using two methods: a densitometric method using a 1.8 g cm^{-3} sodium iodide (NaI) solution and a granulometric method described by Machado[18]. Wet oxidation with potassium dichromate was used for carbon analysis of each soil fraction (C_{sf}) following the method described by Embrapa[19]. The C stocks were estimated as follows: Csf (Mg ha^{-1}) = carbon content (g kg^{-1}) × bulk density (g cm^{-3}) × 5 cm depth/10.

One hundred and thirty days after planting for two consecutive years, the maize was completely harvested from all plots and placed in the open air to dry. The harvested maize was weighed when its moisture content reached 16%.

Data were analyzed using the Statistica software[20]. Analysis of variance was performed, and means were compared using the Tukey test ($P \leqslant 0.05$).

Results and Discussion

Residue quality and nitrogen recycling

In humid tropical agrosystems, the quality and quantity of cover residues strongly affect the rate of decomposition and the time during which the soil is covered. In turn, the availability and the N and K use efficiency rely heavily on the time of soil coverage which enhances the soil rootability[10]. In this experiment, the annual legumes that produced the greatest quantities of biomass were jack bean and sunn hemp, followed by showy rattlebox. In conditions of water stress (during the first year), jack bean outperformed the *Crotalaria* species, but in the second year, the *Crotalaria* species were more productive. The pruning of clitoria at the end of the rainy season in the first year decreased its productivity in the following year. On the other hand, all species except for stylosanthis had higher growth in 2008 than in 2007. This finding is probably due to the greater intensity and more uniform distribution of rainfall at the end of the second year. The highest biomass of the annual legumes compensated for the lower production of the clitoria biomass and increased the quality of residues in the second year compared to the first year (Table 2). In the second year, the clitoria and clitoria+ stylosanthis treatments did not provide enough biomass for soil coverage.

Soil coverage buffers sudden changes in temperature and humidity in this region. This is important because the local soils have a fragile structure and are generally prone to cohesion. Thus, moisture retention makes the soil less hard and improves rooting ability and nutrient use efficiency[10]. The levels of recycled nitrogen followed the normal trend in biomass production. However, potassium recycling was highest with *Crotalaria* species. The efficient use of nitrogen and potassium under humid tropical conditions

Table 2. Dry biomass, nutrient contents and residue quality of the mixture (clitoria + annual species) and of the clitoria, applied to each treatment; average of 2 years.

Parameter	Stylosanthis	Showy rattlebox	Sunn hemp	Jack bean	Clitoria
Year I					
Dry biomass (Mg ha^{-1})	6.20 (± 0.58)	6.90 (± 0.86)	7.70 (± 0.65)	8.51 (± 0.91)	5.61 (± 0.65)
Nitrogen (kg ha^{-1})	174.85 (± 6.90)	197.34 (± 12.91)	225.61 (± 19.32)	233.72 (± 18.85)	155.70 (± 13.90)
Potassium (kg ha^{-1})	17.41 (± 1.89)	24.65 (± 3.00)	17.71 (± 1.90)	20.43 (± 2.54)	14.61 (± 1.51)
C/N ratio	9.03 (± 1.23)	9.11 (± 0.87)	8.97 (± 0.78)	9.05 (± 1.00)	9.09 (± 1.10)
Lignin (%)	15.00 (± 1.17)	14.84 (± 1.20)	13.94 (± 1.45)	12.73 (± 1.30)	15.76 (± 1.45)
Polyphenols (%)	1.25 (± 0.15)	1.16 (± 0.12)	1.00 (± 0.98)	1.13 (± 0.08)	1.30 (± 0.15)
Plant residue quality index	9.33 (± 0.10)	9.55 (± 1.11)	10.21 (± 1.50)	10.53 (± 0.98)	9.24 (± 0.12)
Year II					
Dry biomass (Mg ha^{-1})	2.03 (± 0.19)	5.50 (± 0.76)	6.90 (± 0.71)	5.15 (± 0.47)	1.65 (± 0.11)
Nitrogen (kg ha^{-1})	57.05 (± 4.98)	173.16 (± 16.87)	187.74 (± 16.78)	138.76 (± 12.43)	44.96 (± 3.70)
Potassium (kg ha^{-1})	5.84 (± 0.62)	34.27 (± 2.98)	25.25 (± 2.58)	11.27 (± 1.42)	4.07 (± 0.56)
C/N ratio	9.17 (± 1.09)	9.07 (± 1.32)	8.66 (± 1.11)	9.04 (± 0.87)	9.05 (± 0.83)
Lignin (%)	14.58 (± 1.56)	11.84 (± 1.43)	10.37 (± 0.98)	9.77 (± 0.74)	15.24 (± 1.23)
Polyphenols (%)	1.26 (± 0.12)	0.83 (± 9.23)	0.58 (± 0.61)	0.79 (± 0.86)	1.23 (± 1.71)
Plant residue quality index	9.74 (± 1.43)	10.92 (± 1.56)	12.14 (± 1.15)	12.34 (± 1.35)	9.17 (± 1.00)

Figures in parenthesis indicate standard deviation.

depends on optimal root functioning and the availability of these nutrients during the growth period[21,22]. In a region where rainfall can reach 1200 mm during the crop growth period, nutrient availability is reflected in resistance to vertical movement of surplus water. Therefore, the best coverage treatments for growing crops are those that provide the best rooting conditions and greatest N and K recycling and uptake from residues[10].

Effect on soil organic matter

SOM levels were reduced by the soil management in alley cropping systems with annual legumes relative to the secondary forest area, but the decrease in SOM was even greater in the conventionally tilled area. The largest reductions in the conventionally tilled area were in the clay and silt fractions, with the latter reduced by more than five fold compared to annual legume treatments and by more than eight fold compared to the conventional tillage (Fig. 1). According to Feller and Beare[23], changes in carbon stocks in agriculturally managed soil are dependent on soil texture. In silty soils such as those found in this experiment, greater changes are expected to occur in the silt fraction.

The light fraction supposedly represents an intermediate pool between non-decomposed residues and humified SOM and therefore is not only the less stable fraction, but also the most sensitive to changes in management practices mainly in humid tropical conditions[24]. Several authors[25,26] have reported the high sensitivity of the light fraction to changes caused by management of tropical soils. On the other hand, according to Christensen[27], variations in the light fraction depend primarily on factors that alter the balance between the production and decomposition of residues. Soil tillage in the conventional system and biomass quality in annual legume treatments decreased the SOM light fraction levels in this experiment. The free light fraction is important in tropical silty and loamy soils because of its effect on what Shepherd et al.[28] called the *ephemeral stability of aggregates*, which is reflected in improved physical indicators such as infiltration rate and aeration capacity. These effects can be extremely important in the humid tropics, especially during periods of higher levels of rainfall, when excess water limits plant growth[29]. There were no differences in humified organic matter among any of the treatments. Environmental factors, such as the ready availability of water, oxygen, nutrients and high temperatures, all of which were present in this experiment, can eliminate the differences that varying systems of soil management have on these fractions of organic matter[30].

Capacity to suppress weeds

The lack of effective weed management practices is widely reported to be a major constraint in alternative agriculture[31]. Under Brazilian humid tropical conditions, no-till farming without herbicides is feasible only if farmers can reduce the incidence of weeds that grow from May to August after the long-season crop is harvested. The high growth of the weeds in this period might produce seed banks that infest the crops sown at the beginning of the next rainy season[3]. In this experiment, the presence of annual legumes sown in the first year was not enough to reduce weed incidence in the primary crops in the following year (Table 3). The lack of rain, which discourages the growth of the legumes and the high coefficient of variation, may have been the primary causes of the lack of significant differences between weed biomasses from areas with residues versus the control area.

Several other factors may contribute to the variation of weeds in alley cropping systems, including shading of the area during tree growth, which reduces the abundance of

Table 3. Density and biomass of monocotyledons and dicotyledons, years I and II, and ratio biomass of *Commelina* sp.:total year II in the treatments the mixture (clitoria + annual species) and clitoria alone 30 days after sowing.

	Stylosanthis	Showy rattlebox	Sunn hemp	Jack bean	Clitoria
Year I					
Monocotyledons					
Density (plant m^{-2})	33.5	25.5	52.5	25.2	25.8
Biomass (kg ha^{-1})	1352	822	1398	982	1692
Dicotyledons					
Density (plant m^{-2})	68.0	25.0	52.0	15.2	19.8
Biomass (kg ha^{-1})	560	525	495	505	385
Total					
Density (plant m^{-2})	101.5	50.5	104.5	40.5	45.5
Biomass (kg ha^{-1})	1912	1348	1892	1488	2078
Year II					
Monocotyledons					
Density (plant m^{-2})	70.0	44.0	51.0	46,5	103.0
Biomass (kg ha^{-1})	485	440	415	490	740
Dicotyledons					
Density (plant m^{-2})	51.0 a	16.0 b	25.0 ab	23.5 ab	34.0 ab
Biomass (kg ha^{-1})	190	100	80	110	60
Total					
Density (plant m^{-2})	121.0 ab	60.0 b	76.0 ab	70.0 ab	137.0 a
Biomass (kg ha^{-1})	675	540	495	600	800
Ratio *Commelina* sp.:total biomass (%)	62.2	58.3	70.7	61.6	53.1

Different letters indicate significant differences calculated by Tukey test ($P < 0.05$).

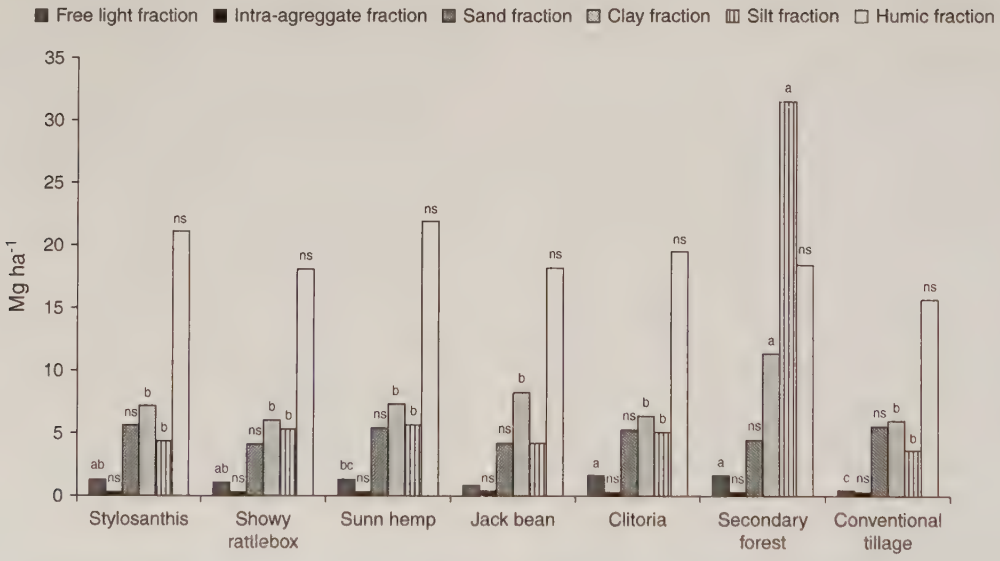

Figure 1. Carbon fraction quantities of the soil under the mixture (clitoria + annual species), clitoria alone, secondary forest and conventional tillage, at a depth of 0–5 cm. Different letters indicate significant differences calculated by the Tukey test ($P < 0.05$). ns = not significant.

species that are sensitive to shade. Also, the improvement in soil fertility indicators resulting from the decomposition of residues applied over time alters the competitiveness of the crop and the composition of weeds[32]. The change in the composition of the weed community in this experiment is evident by comparing these results to those of Araújo et al.[3]. The previous study took place in the same location in 2004 and found more than 60% dominance of weedy Poaceae species, especially *Leptochloa virgata* and *Panicum laxum*. Four years later, in the second year of this experiment, *Commelina* species predominated, comprising more than 58% of weed species in all treatments and

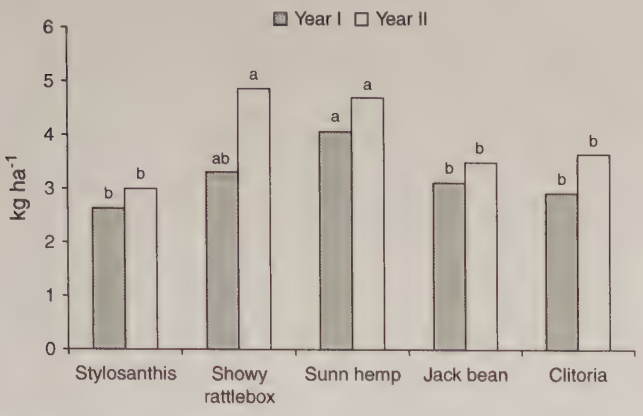

Figure 2. Maize yield in the years I and II and in the treatments the mixture (clitoria + annual species) and clitoria alone. Different letters indicate significant differences by the Tukey test ($P < 0.05$).

reaching as much as 70% in the *C. juncea* treatment. Changes in species composition often occur when management practices and crop rotation systems are altered. Organic carbon levels and nutrient availability are the primary factors that influence the changes in species composition of weeds in cultivated fields[33].

During the second year, although there was greater growth of legumes, the overall weed density was reduced only in the *C. spectabilis* treatment. With this treatment, weed density was reduced to less than half that of the control (Table 3). The impact of soil coverage on weed density is probably related to biological effects of allelopathic products derived from residue decomposition and the physical weed barrier brought about by the presence of the material used for covering the soil surface. The inhibitory effect of *Crotalaria* species on weeds has also been shown[34].

Maize productivity

Despite the low productivity of the annual legumes, used as the green manure, only the residue application of sunn hemp affected maize productivity during the first year (Fig. 2). Productivity increased during the second year in all treatments, but the highest yields were attained with *Crotalaria*. According to Moura et al.[10], the productivity of maize under the conditions of this experiment is determined by the efficiency of absorption and remobilization of N and K, which depend on their availability and the rooting ability conditions provided by soil coverage.

Because side-dressing fertilization was not used, the differences in productivity in this experiment can only be explained by the greater nutrient availability and nutrient use efficiency derived from the annual legumes. In a study in the same region[9], different coverage residues were compared. Those authors concluded that for maize productivity, the application of greater quantities of N and K from high-quality leucaena residues was equivalent to long-term coverage with low-quality residues for the leguminous trees *Inga edulis* and *C. fairchildiana*, both of which produced 48% more than the control treatment without residue application.

Over the 2 years of this experiment, the *Crotalaria* treatments produced more biomass, N and K and produced 30% more grain than control treatments. This indicates that soil covered with lower-quality clitoria residue was less productive than the mixture of residues. Some studies[11] have reported that an appropriate combination of different quality residues can improve uptake from N recycling and that the combination of leucaena (higher quality) with *Acacia mangium* (low quality) grown in alleys can produce up to four times more grain of maize than soil without residues. In this experiment, mixtures of residues with sunn hemp and showy rattlebox performed better in the second year, even with the low quantities of clitoria, because they provided greater quantities of N and six times more K than the control.

Conclusion

Under humid tropical conditions, soil used for farming experiences rapid decreases in total levels of organic matter relative to areas of secondary forest, primarily by decreasing levels of silt and clay fractions. However, the use of legumes in no-till systems may be more environmentally appropriate for compensating for these decreases than conventional systems that reduce the silt and free light organic matter fractions of the soil. Moreover, the soil management in this system changes the composition of the weed community, replacing the more aggressive types (such as the Poaceae species) with those less competitive (such as the *Commelina* species).

From an agronomical point of view, the use of *C. spectabilis* sown at the end of the rainy season seems to be an effective strategy for reducing weed density in the long season crop. Furthermore, relative to the use of leguminous trees alone, there is some evidence that higher yields of maize can be obtained with the use of showy rattlebox and sunn hemp without the application of additional N. In order to design an agrosystem that is appropriate for humid tropical conditions, further research that addresses the sustainability of the beneficial effects of various systems is needed.

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Post-emergence weed control through abrasion with an approved organic fertilizer

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Abstract

Corn gluten meal (CGM) is an approved organic fertilizer and pre-emergence herbicide that can be manufactured in the form of grit. This grit was tested for its ability to abrade seedlings of the summer annual weedy grass, *Setaria pumila*, when plants were in the 1- to 5-leaf stages of growth. CGM was propelled at air pressures of 250–750 kPa at distances of 30–60 cm from the plants. Established seedlings of *S. pumila* were controlled more effectively when grit was applied at 500 and 750 kPa than at 250 kPa, as well as when the applicator's nozzle was 30 cm from the plants compared to 60 cm distance. Seedling growth and dry weights were greatly reduced by exposures to grit at 60 cm and 500 kPa for 2 s or less, and seedlings were nearly completely destroyed at 30 cm distance and 750 kPa. CGM, a soft grit, was as effective for abrading seedlings as fine quartz sand, a hard grit. CGM had little pre-emergence herbicidal effect on *S. pumila*. Although regrowth can occur in *S. pumila* after abrasion by grit, the initial grit-induced stunting is sufficient to allow competing crop plants, like maize, to escape competition and suppress the weed. Consequently, CGM may be an effective form of soft grit for post-emergence abrasion of seedlings of summer annual grass weeds in organic row crops, while simultaneously supplying the crop with fertilizer.

Key words: alternative, control, fertilizer, management, non-chemical, organic, weed

Introduction

Weed control is second only to labor supply as the most serious concern of organic growers[1]. Weeds remain a serious issue even in small organic research plots[2]. Although the benefits of crop rotation, sanitation, etc. for long-term weed management systems are recognized widely by growers, a demand still exists for new and improved tactics for short-term weed control. Despite the existence of several organically compatible forms of weed control, such as flaming, steaming, inhibitory natural products and so forth, most organic growers still rely heavily on repeated soil tillage for weed control. Because soil tillage may diminish soil health, new weed control techniques that do not involve soil disturbance would be welcomed by growers.

Previous work has demonstrated that innocuous grits derived from agricultural residues could be used for post-emergence control of small seedlings of broadleaf weeds[3]. Weed seedlings were controlled by abrasion if grits were propelled from nozzles at air pressures of about 500 kPa. The apical meristems or growing points of most broadleaf weeds are above the soil surface and, consequently, their abrasion and shredding by grits resulted in nearly complete death of small seedlings.

Meristems of grasses typically remain below the soil surface during seedling development for a much longer period of time than those of broadleaf plants. Consequently, air-propelled abrasive grit may not control grass seedlings as effectively as those of broadleaf weed seedlings. In other words, even though the exposed leaves of grass seedlings may be abraded completely by grit, the shredded portions of leaves could be replaced by continual leaf elongation and development from the buried meristems.

Another important issue for organic farmers, besides weed control, is soil fertility, especially soil nitrogen. Most nitrogen in organic systems is supplied through legume-based crop rotations and green and animal manure. Additional sources of nitrogen are desirable, particularly those that can be applied in a flexible and as-needed manner. Rhizobially fixed nitrogen and manures require time and long-term scheduling (e.g., rotations) that may not allow farmers to capitalize on short-term market opportunities. For this and other reasons, protein-rich products have been used by organic farmers for fulfilling nitrogen

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requirements of their crops. These products have included seed meals, i.e., products that remain after oil or starch extraction from seeds of canola, corn, cotton, etc. Traditionally these meals are used as livestock feeds, but some can be used also as organic fertilizers[4,5].

Agricultural residues previously used as grits for weed control included corn (maize) cobs and walnut shells. These materials are comprised mostly of carbohydrates and would be expected to have little effect on soil chemistry other than contributing small amounts of carbon and other elements to soil organic matter. In contrast, corn gluten meal (CGM) is of particular interest as both a grit and a labile organic fertilizer. CGM is a by-product of the wet milling process of maize grain. It contains 9–10% N, and when added to soil it releases this N over 1–4 months[5–7]. CGM could provide N fertilizer, while simultaneously controlling small weed seedlings. Moreover, CGM also may inhibit radical growth of seeds of late-emerging species, such as *Digitaria sanguinalis* L.[8], thereby providing three potential benefits from one application: post-emergence weed control, crop fertility and pre-emergence weed control of late-emerging weeds.

Grit can be derived from maize cobs or CGM. Worldwide 27 countries each produce at least 1 million hectares of maize, with the USA alone harvesting over 30 million ha[9], and even small nations such as New Zealand may produce over 100,000 ha[10]. Consequently, the raw material for grit production is widely available.

Our objectives for the project described here were twofold. The first was to determine if seedlings of a common summer annual grass weed, known as yellow foxtail or yellow bristlegrass (*Setaria pumila* [Poir.] Roem. & Schult. = *S. glauca* [L.] P. Beauv.) could be controlled by timely applications of air-propelled grit. The second goal was to examine CGM for its efficacy as a (soft) grit compared to a traditional hard grit such as fine quartz sand.

Materials and Methods

A series of experiments were performed, each twice, in the outdoor Plant Protection nursery of AgResearch, Ruakura Research Centre, Hamilton, New Zealand. All experimental work was carried out between December 10, 2009 and February 5, 2010. Daily growing conditions during this period were as follows: minimum and maximum air temperatures (± SE), 12.3 ± 0.51°C and 23.2 ± 0.31°C; solar radiation, 23.6 ± 0.87 MJ m^{-2}; and rainfall, 2.9 ± 1.12 mm. In addition, the nursery was irrigated with 6 mm of water by an overhead sprinkler system each morning and afternoon.

Experimental methods common to all experiments are described in this and the following paragraph, whereas specific details for individual experiments are explained separately. All plants were grown in 1.5-litre plastic pots (15 cm diameter) which were filled with 'Daltons GB Potting Mix'. This mix contained a complete source of macro, micro and trace elements needed for the growth of plant seedlings over the course of 4–6 weeks; consequently, no supplemental fertilizer was added. After seeds were sown (see below) on the soil surface, additional potting mix was placed in the pots, resulting in the final soil surface being 1 to 2 cm above the seeds. Pots were thoroughly watered immediately after seeds were sown. Seeds of *S. pumila* were collected from the Waikato District of New Zealand's North Island during the growing season of 2007/2008.

The abrasion of seedlings was performed via a trigger-operated sandblasting nozzle as pictured elsewhere[3]. The nozzle was connected to a 5.6 kW (7.5 horse power) air compressor (LT270, ABAC Co.) with air delivery regulated at 500 kPa. A 250 ml funnel served as the grit reservoir, which was placed above the nozzle and connected to it with a clear nylon hose. Thus, both gravity and suction fed grit into the nozzle when the trigger was squeezed, and the presence of grit or air pockets could be seen through the clear hose and corrected if necessary. The tip of the nozzle typically was positioned 60 cm from the centre of the treated seedlings and at a 30° angle from the horizontal. The nozzle was secured in place with clamps on a burette stand. Grit used for abrasion was the granular formulation of AvonGold CGM (New Zealand Starch, Penford New Zealand Ltd), and fine quartz sand (source unknown). Grit diameters (mm) were approximately 0.3 ± 0.07 for CGM and 0.6 ± 0.07 for sand.

Repetitious abrasion and recovery

In this experiment, we queried whether *S. pumila* (i) can recover from abrasion and (ii) whether abrasion effects differ between CGM (soft grit) and fine quartz sand (hard grit).

Approximately 10 seeds of *S. pumila* were sown in each of 30 pots on December 10, 2009. Treatments were applied on December 21 when each pot had, on average, five seedlings; 40% at the spike stage (0-leaf, 8 mm tall) and 60% at the 1-leaf stage of growth (13 mm tall). At that time 15 pots were selected randomly for the following five treatments, each with three replications: (i) 1 s of abrasion with fine quartz sand, (ii) 2 s abrasion with fine quartz sand, (iii) 1 s of abrasion with CGM, (iv) 2 s abrasion with CGM and (v) the control treatment with 2 s of abrasion with air (no grit) at 500 kPa pressure. The experiment was repeated on December 26 when there were, on average, six seedlings per pot, with 25% at the spike stage (9 mm), 50% at the 1-leaf stage (15 mm) and 25% at the 2-leaf stage (20 mm).

Injury due to abrasion was rated visually 7 days after treatment on a score of 0 to 10, with 0 indicating no effect compared to control plants and 10 indicating complete death. All plants in each pot also were measured at that time for maximum height above the soil level of living green tissue. Subsequently, each pot was treated again, and this sequence was repeated at weekly intervals for two additional weeks. One week after the third abrasion, the plants were scored and measured as above and then

harvested. Plants were cut at the crown, dead leaf tissues carefully excised, dried at 60–80° C for 2 days and weighed to the nearest 0.1 mg.

Abrasion duration and distance

The purpose of this experiment was to explore the effects of (i) the duration of grit abrasion and (ii) the proximity of the weed to the 28 grit source.

Approximately ten seeds of *S. pumila* were sown in each of the 54 pots on December 10, 2009 and, subsequently, seedlings were thinned to four per pot. On December 30, when seedlings were at the 2- to 3-leaf stage of growth, they were subjected to the following treatments, each with three replications: (i–v) 1, 2, 3, 4 or 5 s abrasion by CGM at 60 cm distance between nozzle and seedlings; (vi–x) as above but at 30 cm distance between nozzle and seedlings; (xi) 5 s of air (no grit) at 30 cm; and (xii) control (i.e., no grit or air). Visual injury was rated 1 week after treatment (January 6, 2010), as was the maximum height of the living green tissue of each plant. Plants were harvested and processed as described earlier. The experiment was repeated, with seed sowing on January 6, 2010, treatments occurring on January 19, and measuring and harvesting on January 28.

Air pressure effects

In this experiment, we explored the effects of differing (i) air pressures and (ii) distances of the weed from the grit source.

Twenty seeds of *S. pumila* were sown in pots on January 6, 2010, thinned to four seedlings per pot, and treated on January 29, 2010 when the plants were at the 4- to 5-leaf stages of growth and were 67 ± 3.7 mm tall. Main treatments involved air pressure at 250, 500 and 750 kPa for propelling CGM grit. Sub-treatments were 30 and 60 cm distances between the nozzle and the potted seedlings. There were three replications per sub-treatment. Grit was applied for 5 s duration to each pot. Control pots received 5 s of air only at 500 kPa pressure at 30 cm distance. Injury was evaluated 1 week after treatment, at which time heights of all surviving plants were measured. At this same time, green tissues were cut at the soil surface, dried and weighed as above. The experiment was repeated with a different set of pots the same day.

Selective control in maize

In this experiment, maize was tested as a 'model' crop to document whether a weed could be selectively controlled without adversely affecting crop growth.

Twenty seeds of *S. pumila* and five seeds of maize (Pioneer '36H36') were sown into each of 16 pots on December 10, 2009. (Maize did not emerge adequately in a repeated experiment, which was abandoned.) Subsequently, pots were thinned to four *S. pumila* seedlings and one maize seedling per pot. All weed seedlings were rooted within 5 cm distance of the maize seedling. The four treatments were as follows: (i) at the 2-leaf, (ii) 3-leaf and (iii) 4-leaf stages of maize, the weed seedlings of four pots were subjected to 5 s of abrasion by CGM grit; and (iv) weed seedlings in four other pots were exposed to 5 s of compressed air, but not grit, which represented the control treatment. The nozzle was spaced 60 cm from the seedlings and at a 30° angle from the horizontal, which created an oval spray pattern of about 10 × 13 cm (data not shown), which means that the bases of the maize plants as well as the weeds were affected by the grit. Leaf stages and heights of all seedlings were recorded immediately prior to treatments. Visual injury to maize and weeds was rated 1 week after each treatment, as was the height of living green tissue of each plant. Maize and weeds were cut at the soil level 1 week after the 4-leaf treatment, dried at 70°C for 1 week and weighed.

Grit delivery rate

This experiment was necessary to determine the amount of grit propelled per second at 500 kPa by the applicator in the above experiments.

The rate of grit delivery was measured by placing the burette stand and all attached items, including the funnel full of grit, onto a balance and weighing the entire apparatus before and after 5 s of abrasion each of four times for both sand and CGM grits. Means and standard errors were calculated for grit deliveries per second for each grit type.

Effects of CGM without air pressure

Because evidence exists for CGM to behave as a pre-emergence herbicide[8,11], its effects on *S. pumila* seedling emergence and growth were examined.

The experiment began on December 10, 2009, wherein about ten seeds of *S. pumila* were sown in each pot. The six treatments were as follows, each with three replications: 0, 1.8, 4.4, 8.8, 17.7 and 44.2 g pot^{-1} of CGM spread evenly on the surface of the pots 1 day after the seeds were sown. These rates were equivalent to 0, 100, 250, 500, 1000 and 2500 kg ha^{-1} of CGM. The experiment was repeated on December 30 with exactly 20 seeds of *S. pumila* in each pot. The number, leaf stage and heights of all seedlings were recorded on December 29 for Experiment 1 and January 19 for Experiment 2.

Statistical analyses

In each experiment, pots were arranged in a randomized complete block design after treatment. Statistical analysis of categorical data involved analysis of variance (ANOVA)[12]. Each experiment was repeated in time, and in the absence of significant ($P < 0.05$) experiment × treatment interactions, the data for both experiments were combined. Non-linear regression was used to examine and summarize continuous data. If regression parameters did

Table 1. Average effects (± SE) of 1 or 2 s of air-propelled sand or CGM grit on injury and heights of *S. pumila* seedlings 1 week after each of three successive weekly treatments, as well as final shoot dry weights. For visual injury, ratings are back-transformed means followed by Tukey's HSD groupings across treatments; invariant ratings for control plants were not included in ANOVA.

Week	Sand 1 s	Sand 2 s	CGM 1 s	CGM 2 s	Control	*P*
	Injury (0 to 10, 10 = dead)					
1	6.2	6.0	6.8	6.8	0	NS
2	8.6	8.6	7.4	8.3	0	NS
3	9.0 ab	9.5 a	8.2 b	9.1 ab	0	<0.01
	Cumulative height (mm) of all living plants per pot					
1	120 ± 7.4	150 ± 25.7	166 ± 31.6	149 ± 31.8	213 ± 15.6	NS
2	142 ± 11.1	157 ± 39.3	208 ± 43.7	193 ± 37.4	374 ± 30.7	<0.01
3	166 ± 16.9	174 ± 53.7	233 ± 53.7	221 ± 52.2	542 ± 51.4	<0.01
	Dry weight (mg) of aboveground green tissues per pot					
3	44 ± 5.8	37 ± 9.7	89 ± 19.5	58 ± 13.8	570 ± 48.8	<0.01

Means not followed by letters in common differ significantly.

not differ ($P>0.05$) between experiments, data were aggregated and parameters compared only between treatments. Otherwise, experiments were analyzed separately.

Injury ratings were divided by 10 and then the arcsine-square root transformed prior to statistical analyses, but back-transformed for presentation. Because standard errors are difficult to report for back-transformed means, Tukey's honest significant difference (HSD) was used for grouping back-transformed injury values.

Results

Repetitious abrasion and recovery

Although injury levels differed between experiments, no interactions occurred between experiments and treatments. Consequently, data for the two experiments were combined (Table 1). Visual injuries to *S. pumila* seedlings 1 week after abrasion treatments ranged from 6.0 to 6.8 at week 1, 7.4 to 8.6 at week 2 and 8.2 to 9.5 at week 3. Differences in the duration of grit application were not apparent. The only significant difference occurred at week 3 when 1 s of CGM was found to injure seedlings less than 2 s of sand. However, a trend of increasing intensity of injury over time was apparent for each grit treatment.

In all grit treatments, cumulative maximum heights of green tissue of all living plants within each pot were shorter than those in the control treatment in weeks 2 and 3. However, heights were equivalent in all grit-treated pots. Cumulative height of all living plants was a non-destructive measurable variable and was less subjective than visual injury ratings. Both variables allowed comparisons of the same plants over time.

At the final harvest, dry weights of plants closely reflected both measured plant heights and estimated injury levels. Grit treatments did not differ among themselves, but each differed from the control treatment. Relative to control plants, treatments reduced dry weights by 84–94%. Consequently, the results of all three variables signified that (i) a soft grit-like CGM is as effective as a hard grit in terms of severity of damage inflicted on seedlings, (ii) 1 s of grit delivery works as well as 2 s and (iii) good control of grass seedlings may require more than one grit application.

Abrasion duration and distance

Visual injury, seedling height and dry weight of seedlings were highly correlated to one another in terms of the effects of the duration of abrasion by grit and the distance of the nozzle from the plants (data not shown). Consequently, only results for plant dry weights are described below.

Plants attained different weights in response to abrasion in the two experiments. These differences were detected readily through best-fit non-linear asymptotic regressions ($P<0.05$, F distributions >20). Therefore, data for each experiment were analyzed and presented separately. Differences were likely due to daily air-temperature and time-span disparities: i.e., 16.4 ± 0.43°C over 18 days in Experiment 1 (smaller plants) and 18.0 ± 0.53°C over 23 days in Experiment 2 (larger plants).

Despite the differences between experiments, similar trends were apparent in response to abrasion duration and distance (Fig. 1). A single abrasion event for one or more seconds of CGM grit injured seedlings of *S. pumila*, but for each experiment the level of injury was much greater ($P<0.05$) when the nozzle was placed at 30 cm distance from the seedlings than at 60 cm distance. When plants were exposed to more than 1 s of abrasion by grit, slight additional loss in dry weight occurred.

Dry weight reductions were related to the duration of grit application in a non-linear manner. Best-fit asymptotic equations for each distance in each experiment (Ex) were as follows: (Ex 1, 30 cm) $mg = 6.3209 + 133.64 \times 0.2063$ kPa, $r^2 = 0.99$; (Ex 2, 30 cm) $mg = 15.847 + 248.67 \times 0.212$ kPa, $r^2 = 0.98$; (Ex 1, 60 cm) $mg = 53.765 + 123.85 \times 0.2045$ kPa, $r^2 = 0.98$; (Ex 2, 60 cm) $mg = 70.894 + 402.77 \times 0.2479$ kPa, $r^2 = 0.94$. Each equation differed significantly ($P<0.05$) from the others.

Compared to plants treated with neither grit nor air, dry weights of plants treated with 5 s of air only at 500 kPa

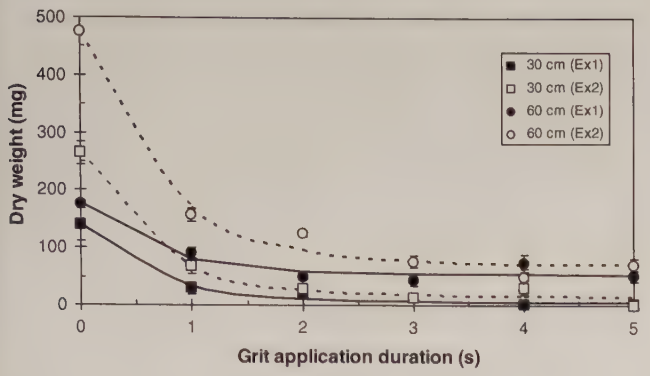

Figure 1. Dry weights of *S. pumila* seedlings 1 week after abrasion by CGM grit for 1–5 s at 500 kPa when the applicator nozzle were either 30 cm or 60 cm from the target plants. Results from two experiments (Expts) are shown. Vertical bars represent ± SE.

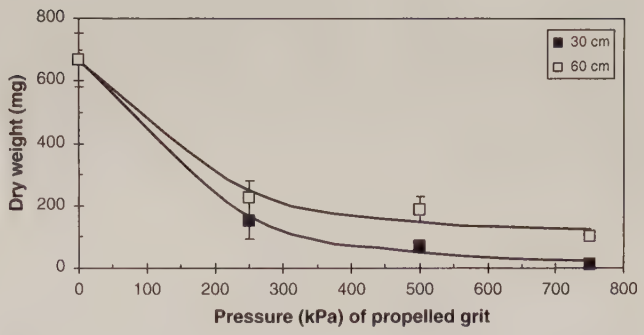

Figure 2. Dry weights of *S. pumila* seedlings after treatment with CGM grit propelled at different air pressures when the applicator nozzle was spaced at 30 or 60 cm from the target plants. Vertical bars represent ± SE.

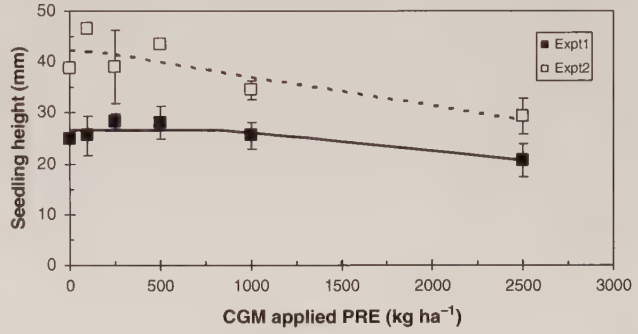

Figure 3. Effect of CGM applied as a pre-emergence herbicide on average seedling height in two experiments. Vertical bars represent ± SE.

were reduced significantly ($P < 0.05$) by 64 ± 3.2% at 30 cm distance and 52 ± 9.1% at 60 cm distance. We speculate that the reduction in dry weight of plants exposed to 5 s of air only was due to abrasion by dislodged and airborne potting soil rather than the air itself. Abrasion by 1 or 2 s of air only was not obvious in any of our experiments. The difference between the two distance treatments in the absence of grit was marginal ($P = 0.09$).

These results indicate that nozzles placed 30 cm from weed seedlings are more effective than those placed at 60 cm. Moreover, increasing the duration of abrasion by grit beyond 1 or 2 s had little additional effect on injury, height reduction or dry weight decrease. Additionally, although abrasion by air alone for 5 s reduced plant dry weights, the addition of grit to the air stream for just 1 s substantially reduced dry weights even more.

Air pressure effects

Visual injury and cumulative plant height were closely related to the dry weight of *S. pumila* seedlings, thus only results for dry weights are shown in Fig. 2. Because results from each experiment did not differ ($P > 0.05$), data were combined. Dry weights (mg) of plants at each nozzle distance fit separate non-linear asymptotic relationships with respect to differing air pressures. The associated equations were (30 cm) $mg = 16.161 + 649.55 \times 0.9942^{kPa}$ ($r^2 = 0.86$) and (60 cm) $mg = 116.26 + 548.65 \times 0.9944^{kPa}$ ($r^2 = 0.91$). The two equations differed ($P = 0.05$) significantly with a calculated F distribution value of 3.2.

Dry weight reductions were greater when the nozzle was spaced 30 cm from the plants than 60 cm under each pressure regime. Dry weight reductions also increased with air pressure, but at decreasing rates once 250 kPa was exceeded. At the highest pressure and closest distance (750 kPa and 30 cm), injury was sufficient to cause nearly complete plant death.

Selective control in maize

Maize height at harvest averaged 36 ± 1.2 cm and did not differ among treatments ($P > 0.1$). Maize leaf developmental stage did differ among treatments ($P < 0.05$), but only slightly, with the control, 2-leaf, 3-leaf and 4-leaf treatments attaining 5.6 ± 0.05, 5.8 ± 0.05, 5.9 ± 0.03 and 5.9 ± 0.03 leaves per plant, respectively. The control plants were smaller than the plants in the 3- and 4-leaf treatments, but were equivalent to plants in the 2-leaf treatments. The 2-, 3- and 4-leaf treated plants had equivalent stages of leaf development. Maize dry weights also differed ($P = 0.01$) among treatments. The average maize seedling dry weights at harvest were 1.4 ± 0.10, 2.5 ± 0.24, 2.1 ± 0.24 and 2.3 ± 0.15 g for the control, 2-leaf, 3-leaf and 4-leaf treatments, respectively. The control plants weighed less than the 2- and 4-leaf plants, but were equivalent to the 3-leaf plants. Weights of the 2-, 3- and 4-leaf plants did not differ.

At the final harvest, weights of *S. pumila* differed significantly ($P < 0.01$). *S. pumila* plants in the control, 2-leaf, 3-leaf and 4-leaf treatments weighed 1.3 ± 0.14, 0.4 ± 0.09, 0.6 ± 0.02 and 0.8 ± 0.03 g, respectively. The control plants were heavier than the other treatments, which had equivalent weights. These results are based on a single

experiment and should be viewed cautiously. Nevertheless, they suggest that grit applications when maize is in the 2-leaf through 4-leaf stages of growth will curtail growth of *S. pumila* and allow maize to grow better than when weeds are not controlled.

Grit delivery rate

The grit delivery rate was $7.2 \pm 0.38\,g\,s^{-1}$ for fine quartz sand and $4.7 \pm 0.21\,g\,s^{-1}$ for CGM at an air pressure of 500 kPa. To estimate how much grit would be needed to control weeds within and alongside crop rows, several assumptions were made, which included: crop rows were spaced at 75 cm, the applicator had twin nozzles to affect control on either side of the row and the applicator traveled at $1\,km\,h^{-1}$. Given these assumptions, $445\,kg\,ha^{-1}$ of CGM or $682\,kg\,ha^{-1}$ of fine quartz sand would have been applied.

For comparison, when used as an organic fertilizer, rates of approximately 1000–2000 kg CGM ha^{-1} are recommended (100–200 kg N ha^{-1})[7]. Thus, even if the speculative calculated rate of 445 kg CGM ha^{-1} for weed control is two to four times too low, it still is within the range of recommended rates for use as an organic fertilizer.

Effects of CGM without air pressure

The rate of CGM applied pre-emergence did not affect *S. pumila* emergence (data not shown). However, seedling heights (mm) decreased slightly when fit to a Farazdaghi–Harris equation[12] (pseudo $r^2 > 0.99$, $P < 0.01$). Equation parameters differed significantly for each experiment (Fig. 3), perhaps because of a seemingly minor difference in average daily air temperatures during the experimental periods: 16.4 ± 0.52°C over 19 days in Experiment 1 and 16.9 ± 0.51°C over 20 days in Experiment 2. Parameters for the equations were as follows: Expt 1, $mm = 1/(0.0375 + 0.00000000001185 \times rate^{2.635})$ and Expt 2, $mm = 1/(0.0236 + 0.0000003201 \times rate^{1.3378})$, where rate is in kg of CGM ha^{-1}.

These best-fit equations indicated that seedling heights decreased by 10% from maximum estimated values between 850 and 1750 kg CGM ha^{-1} in the two experiments. This suggests that even high CGM rates affect seedling height growth very little. Whatever the case, CGM did not influence density or growth of *S. pumila* as extensively as it may affect some other weedy grasses[5]. Consequently, the effects on *S. pumila* by abrasive CGM grit observed in the prior experiments are likely due entirely to abrasion rather than chemical inhibition of decomposing CGM.

Conclusions

Our experiments represent 'proof-of-concept' only. They showed that the control of a summer annual grass, such as *S. pumila*, is amenable to abrasion during early seedling development. Furthermore, abrasion can be performed by post-emergence application of CGM, a substance already approved as an organically appropriate form of nitrogen fertilizer and pre-emergence herbicide[7]. Although efficacy as a pre-emergence herbicide may be questionable, simultaneous post-emergence weed control and fertilizer application could be beneficial for organic growers. Lastly, even though maize was used successfully as a model crop in our experiments, we emphasize that weed abrasion by air-propelled grit may be more appropriate in higher value row crops, such as organically managed vineyards, orchards and soft fruit and vegetable production fields, or in non-crop areas such as urban sidewalks[13]. Much additional research will be needed before air-propelled grit can be recommended as a form of organic weed management. For instance, slight but unavoidable damage to adjacent crops may provide entry points for plant pathogens and thereby compromise abrasion by grit as a useful tool for weed control. Nevertheless, the results reported here reveal an encouraging trend for the successful application of the technique.

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Hispanic consumers' perceptions toward locally grown ethnic produce: A study from the east-coast US

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Abstract

The purpose of this study was to predict Hispanic consumer's willingness to buy ethnic produce grown on local farms. Specifically, this result analyzes and compares the effects of Hispanic consumers' socio-economic characteristics and their expressed value judgments on their willingness to buy locally grown ethnic fruits and vegetables. The survey instrument asked respondents whether they were willing to buy ethnic produce grown on local farms, and based on this, an ordered probit model was developed to predict the willingness to buy ethnic produce grown on local farms. The model has significant explanatory power with 80% overall model prediction success. According to the survey results, overall, 80% of the Hispanic respondents were willing to buy locally grown ethnic produce, 13% of them were indifferent and only 7% of them were less willing to buy. The high positive percentage indicates the intensity of consumers' interest toward willing to buy locally grown produce. The study results indicated that growing demand for Hispanic ethnic produce provides a potential opportunity for farmers in the region.

Key words: locally grown, Hispanic ethnic consumer, fruits and vegetables, produce, ordered probit model

Introduction

Most of the northeast farmlands are classified as small farms. Rapid urbanization and continued land development on the east-coast US have put pressure on profitability in agricultural production. Referring to New Jersey in this context, between 1987 and 1997 there was a 6.9% drop in the total farmland acreage[1]. This puts New Jersey farmers at a competitive disadvantage against larger commodity growers from other states where production costs are comparatively lower. There is a need to look for alternative and high-valued or specialty/ethnic crops with competitive advantages. Specialty and ethnic vegetables are defined as vegetables and/or herbs that are not traditionally grown in the US but are imported to the US and are currently grown on a limited scale in the US (e.g., Chili Jalapeno, Tomatillo, Calabacita, Aji Dulce and Batata).

According to the Census Bureau of the United States, the Hispanic population mushroomed by 58% from 1990 to 2000, making it the fastest-growing minority group in the US. The Hispanic or Latino population grew from about 9% of the country's population in 1990 to 13% in 2000, with 35 million people (Census 1990[2] and 2000[3]). It is projected that the Hispanic population will make up 30% of the US population in 2050 (US Census Bureau[4]). Therefore, it is important to explore the potential market opportunities for local producers of ethnic products in targeting Hispanic consumers. This information would prove useful for not only east-coast producers, but also producers in other states and regions experiencing rapid growth in minority populations, especially Hispanics. The growth of Hispanics is largely being fueled by immigration. The growing immigrant population also brings about a niche market demand for familiar foods of their homelands[5,6]. This creates a market for such produce fueled by the increasing number of consumers eager to purchase them. The increasing immigrant population has also led to an increase in the number of produce stores that cater to the ethnic population in the region. Studies conducted throughout the region have shown that growing demand for ethnic produce provides a potential opportunity for farmers in the region[1,7–10].

In recent years, consumers have been showing much interest in locally grown produce. There are several reasons to buy locally grown produce items. The consumption

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of locally grown produce not only supports local farms but also provides fresh produce to consumers within hours after harvest. The local produce is fresh and much tastier than produce sold in a traditional grocery store[11]. Consumers are gradually becoming aware of the flavor, freshness and quality of locally grown produce items, and learning about the nutritional value of foods. Local foods are generally healthier, because they are not extensively processed with preservatives and chemicals. Normally, small-scale farmers do not use chemicals and preservatives, because they are more concerned with quality rather than quantity of the foods they produce[12]. The survival of industrial agriculture largely depends on the low-energy prices and cannot continue for ever. The term 'food miles' refers to the distance food travels in order to reach the ultimate consumer. According to Hendrickson[13], the average fresh food travels 1500 miles to reach consumers. The transportation of fresh produce uses a substantial amount of non-renewable energy resources[14]. Most of the fresh produce is transported by truck and the transportation cost of produce is making the US increasingly dependent on foreign oil resources. The US food system accounts for about 16% of the total US energy consumption[15,16], and much of this energy is derived from burning fossil fuels that release carbon dioxide and other greenhouse gases. The sale of local produce at local markets reduces the usage of transport fuel and protects biodiversity.

Farmers' markets have been playing an important role in selling locally grown foods. Consumer awareness and interest in local foods indicate the continued growth of the number of farmers' markets, which increased from 1775 in 1994 to 5274 in 2009[17]. This trend makes grocery chains sell locally grown products[18,19].

In addition, all the state's agricultural departments in the US increased participation in promoting locally grown foods to support local agriculture. Previous research suggested that at least some of these state-sponsored programs have been successful. In the case of New Jersey, the Jersey Fresh program showed a $32 return for produce growers for every dollar invested in the program[20]. The small farmers and the local economy have been receiving greater benefits by selling local foods. The Northeast Ohio Foodshed Network estimates that for every dollar spent on local food purchases, $1.94 to $3.98 additional dollars flow into the local economy[12].

The above-mentioned reasons influence the consumer's overall purchasing decisions. Most consumers look for attributes such as buying locally, promoting good health, protecting the environment and supporting the local economy. Since no information has been documented about the exact magnitude and drivers of Hispanic consumer preferences toward locally grown products, this study cited general consumers' preferences. A survey conducted in Iowa, Missouri, Nebraska and Wisconsin shows that consumers were interested in buying locally grown produce[21]. The Jersey Fresh program is one of the leading examples of state-sponsored agricultural promotion to encourage locally grown produce. According to the survey results of New Jersey, respondents had a preference for Jersey Fresh produce and indicated that they believed it to be better than other produce in terms of quality and freshness[22]. The objective of this study is to identify and estimate the influence of Hispanic ethnic consumers' socio-economic and value attributes on their behavior and perceptions toward produce grown on local farms.

Conceptual Framework

Hispanic ethnic consumers face a choice between willingness (W) and indifference (D) to buy locally grown fruits and vegetables. Utilities derived from buying local are given by U_W and U_D, respectively, which are not observable. The observable variables are process attributes a ($a = W, D$) and a vector of consumer characteristics (x). The utility of consumer i is postulated as follows:

$$U_{ai} = V_{ai} + \varepsilon_{ai}, \quad (1)$$

where U_{ai} is the latent, unobserved utility for choice alternative a, V_{ai} is the explainable part of the latent utility that depends on the chosen process with attributes a and personal characteristics of consumer i, and ε_{ai} is the random or 'unexplainable' component of the latent utility associated with the choice of product attribute a and consumer i.

Consumer i's choice ordering between willingness and indifference towards locally grown fruits and vegetables (i.e., between attributes W and D, respectively) is modeled in the following way: consumer i ranks local produce in one of the three categories based on the indicator function:

$$Z_i = (V_{Wi} + \varepsilon W) - (V_{Di} + \varepsilon_{Di}) = (\varepsilon_{Wi} - \varepsilon_{Di}) - (V_{Wi} - V_{Di}), \quad (2)$$

where Z_i can be interpreted as the additional utility derived by ith consumer by choosing to buy locally grown produce over indifference. A consumer expresses his/her willingness to buy locally grown produce if Z_i is below some threshold value (e.g., μ_1), shows indifference if Z_i is above μ_1 but below another threshold value μ_2 and reveals willingness to buy produce if Z_i is above μ_2. Formally, consumer i's choice ordering (denoted by Y_i, where $Y = 1$ implies willing to buy produce, $Y = 2$ implies indifference and $Y = 3$ implies less willing to buy produce) can be expressed as follows:

$$\begin{aligned} Y_i &= 1 \quad \text{if } Z_i < \mu_1, \\ Y_i &= 2 \quad \text{if } \mu_1 < Z_i < \mu_2, \\ Y_i &= 3 \quad \text{if } Z_i > \mu_2. \end{aligned} \quad (3)$$

Since part of the utility is random in nature, a researcher cannot perfectly predict the choice of a consumer. From the researchers' perspective, the problem is inherently stochastic, which naturally leads to formulating the ith consumer's choice problem in probability terms:

$$\begin{aligned} p(Y_i = 1 | \text{ChoiceSet}) &= P[Z_i = (\varepsilon_{Wi} - \varepsilon_{Di}) - (V_{Wi} - V_{Di}) < \mu_1], \\ p(Y_i = 2 | \text{ChoiceSet}) &= P[\mu_1 < Z_i = (\varepsilon_{wi} - \varepsilon_{Di}) - (V_{wi} - V_{Di}) < \mu_2], \\ p(Y_i = 3 | \text{ChoiceSet}) &= P[Z_i = (\varepsilon_{wi} - \varepsilon_{Di}) - (V_{Wi} - V_{Di}) > \mu_2]. \end{aligned} \quad (4)$$

Table 1. Description of explanatory variables.

Sl. No.	Variable	Description	Mean/ percent	Standard deviation
1	VISIT_TIMES	Number of times to purchase fruits and vegetables within a month	3.79	2.94
2	ETH_SPND	Expenditure on ethnic fruits and vegetables for visit	22.26	19.03
3	ETH_BUY_AMER	1 if the respondents purchased all ethnic fruits and vegetables from a typical American grocery store; 0 = otherwise	28%	0.45
4	DISTANCE	Ethnic store distance from the respondent home	13.68	20.60
5	STORE_AVBL_IMP	1 if store availability attribute is very important; 0 = otherwise	68%	0.47
6	LANG_IMP	1 if language attribute is very important; 0 = otherwise	40%	0.49
7	PRICE_IMP	1 if price is very important; 0 = otherwise	62%	0.49
8	PACKG_NOTIMP	1 if packaging is not important; 0 = otherwise	25%	0.43
9	FRESHNESS_BETTER	1 if the freshness of the produce is better in ethnic store when compared with others; 0 = otherwise	37%	0.48
10	PRICE_BETTER	1 if the price of the produce is better in ethnic store when compared with others; 0 = otherwise	45%	0.50
11	PACKG_SAME	1 if packaging of produce to be same in the ethnic store when compared with others; 0 = otherwise	54%	0.50
12	ORGNIC_MORE_WTOBUY	1 if the respondent is willing to buy organically grown produce; 0 = otherwise	56%	0.50
13	COOL_WTOBUY	1 if the respondent is willing to buy when the country-of-origin label is available; 0 = otherwise	47%	0.50
14	NEWMRKT_MORE_WTOBUY	1 if the respondent is willing to buy when recently introduced or new to the market; 0 = otherwise	55%	0.50
15	OUT_STORE_ADD	1 if the respondent is influenced by out-of-store ads; 0 = otherwise	55%	0.50
16	YEARS_LIVE	Years living at the current location	13.06	12.03
17	HSIZE	Household size	3.86	1.83
18	BELOW17	Number of children below 17-years age group	1.43	1.40
19	LESS12GRADE	1 if the respondent education is less than 12th grade; 0 = otherwise	11%	0.31
20	HSCHOOL	1 if the respondent education is high school; 0 = otherwise	35%	0.48
21	INC_LES20	1 if the respondent income is less than $20,000; 0 = otherwise	19%	0.39
22	INC_40TO60	1 if the respondent income is between $40,000 and 59,999; 0 = otherwise	22%	0.42
23	INC_80TO100	1 if the respondent income is between $80,000 and 99,999; 0 = otherwise	8%	0.27
24	FEMALE	1 if the respondent is female; 0 = otherwise	77%	0.42

Under the assumption that the random term $(\varepsilon_{wi}-\varepsilon_{Di})$ follows the standard normal distribution, the above probabilistic model is the well-known ordered probit model.

In an empirical estimation, the indicator Z_i for the ith consumer is modeled as a function of his/her socio-economic and value attributes and can be expressed as

$$Z_i = \boldsymbol{\beta}'\mathbf{X} + \nu_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_k x_{ik} + \nu_i, \quad i = 1, 2, \ldots, n, \tag{5}$$

where x_{ij} is the jth attribute of the ith respondent, $\boldsymbol{\beta} = (\beta_0, \beta_1, \ldots, \beta_k)$ is the parameter vector to be estimated and ν is the random error or disturbance term. The model explanatory variables are explained in Table 1. In this setting, the probabilities of choice for $Y_i = 1$, 2 and 3 are given by

$$\begin{aligned} P(Y_i = 1|\text{ChoiceSet}) &= \Phi(\mu_1 - \beta' X_i), \\ P(Y_i = 2|\text{ChoiceSet}) &= \Phi(\mu_2 - \beta' X_i) - \Phi(\mu_1 - \beta' X_i), \\ P(Y_i = 3|\text{ChoiceSet}) &= 1 - \Phi(\mu_2 - \beta' X_i), \end{aligned} \tag{6}$$

where Φ is the cumulative function of a standard normal distribution. In the above model, the μ's are unknown threshold parameters that separate the adjacent rankings or categories. In the empirical estimation stage, both the $\boldsymbol{\beta}$-vector and the μ's are estimated jointly using the maximum likelihood (ML) procedure[23].

The estimated β-coefficients of equation (5) does not directly represent the marginal effects of the independent variables on the probabilities of choice. The marginal effects are given by the following expression (assuming continuous explanatory variables):

$$\begin{aligned} \frac{\partial(Y_i = 1)}{\partial X_j} &= \phi(\mu_1 - \beta' X)\beta_j, \\ \frac{\partial(Y_i = 2)}{\partial X_j} &= \phi(\mu_1 - \beta' X) - \phi(\mu_2 - \beta' X)\beta_j, \\ \frac{\partial(Y_i = 3)}{\partial X_j} &= \phi(\mu_2 - \beta' X)\beta_j, \end{aligned} \tag{7}$$

where ϕ is the density function of the standard normal variable. In the case where the explanatory variable is discrete or categorical in nature, the marginal effect of such a variable is obtained by evaluating the probabilities at

alternative values of x_{ij}. The coefficient estimates are not equal to the marginal effects of the explanatory variables x on the probabilities. The marginal effects of the explanatory variables are calculated in the following manner:

$$\frac{\partial \text{prob}[\text{cell}j]}{\partial x_i} = \left[f\left(\mu_{j-1} - \beta' x_i\right) - f\left(\mu_1 - \beta' x_i\right)\right] \times \beta, \quad (8)$$

where $f(.)$ is the standard normal density. The marginal effects of the dummy variables are calculated as the difference between two resulting probabilities when the dummy variable equals its two values 0 and 1 (Nayga et al.[24]).

The following empirical model is used to estimate the relation between the probability of consumer perception toward willingness to buy produce grown on local farms and his/her personal attributes:

$$\begin{aligned} Y_i = {} & \beta_0 + \beta_1 \text{ VISIT\_TIMES} + \beta_2 \text{ ETH\_SPND} \\ & + \beta_3 \text{ ETH\_BUY\_AMER} + \beta_4 \text{ DISTANCE} \\ & + \beta_5 \text{ STORE\_AVBL\_IMP} + \beta_6 \text{ LANG\_IMP} \\ & + \beta_7 \text{ PRICE\_IMP} + \beta_8 \text{ PACKG\_NOTIMP} \\ & + \beta_9 \text{ FRESHNESS\_BETTER} + \beta_{10} \text{ PRICE\_BETTER} \\ & + \beta_{11} \text{ PACKG\_SAME} + \beta_{12} \text{ ORGNIC\_MORE\_WTB} \\ & + \beta_{13} \text{ COOL\_MOREWTB} + \beta_{14} \text{ NEWMRKT\_WTB} \\ & + \beta_{15} \text{ OUT\_STORE\_ADD} + \beta_{16} \text{ YEARS\_LIVE} \\ & + \beta_{17} \text{ HSIZE} + \beta_{18} \text{ BELOW17} + \beta_{19} \text{ LESS12GRADE} \\ & + \beta_{20} \text{ HSCHOOL} + \beta_{21} \text{ INC\_LES20} + \beta_{22} \text{ INC\_40TO60} \\ & + \beta_{23} \text{ INC\_80TO100} + \beta_{24} \text{ FEMALE}, \end{aligned}$$

where $Y_i = 0$ if the respondent is willing to buy locally grown produce, $Y_i = 1$ if the respondent is indifferent to buying locally grown produce and $Y_i = 2$ if the respondent is less willing to buy locally grown produce.

The vector of explanatory variables in equation (5) included socio-economic and demographic characteristics of the Hispanic consumer as well as variables related to consumers' perceptions and motivation. The socio-demographic characteristics of Hispanic consumers included in equation (5) were expected to be similar to those influencing consumer expenditures on fruits and vegetables in general (e.g., Nayga[25]) and those included in other analyses of consumer preferences for local products (e.g., Jekanowski et al.[26]). In addition, consumer perceptions and motivations toward locally grown Hispanic ethnic produce items were also hypothesized to influence their choice.

Data Description

The data were collected from an ethnic produce survey prepared for Hispanic ethnic group including Mexicans and Puerto Ricans. Sixteen states (Connecticut, Delaware, Florida, Georgia, Massachusetts, Maryland, Maine, North Carolina, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, South Carolina, Vermont and Virginia) and Washington DC were selected from east-coast US and based on random sampling, 541 respondents were interviewed by a private company to collect data using a computer-assisted telephone survey in 2006. In addition to consumer-valued attributes and attitudes, respondents were asked about perceptions pertaining to willingness to buy produce grown on local farms. Residents in the household who were primarily responsible for produce purchasing decisions were interviewed.

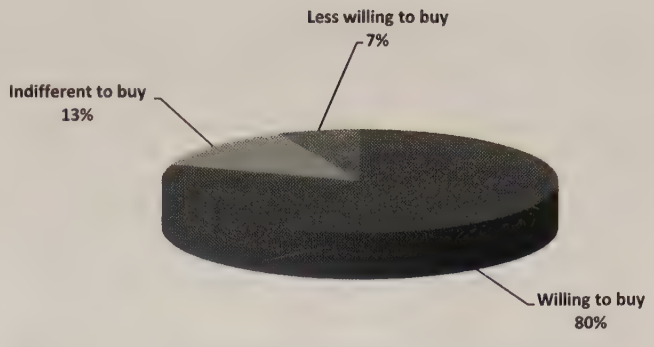

Figure 1. Hispanic ethnic respondents' intensity of willingness to buy locally grown produce.

Summary Statistics

According to the survey results, overall, 80% of the respondents were willing to buy locally grown produce, 13% of them were indifferent to buying locally grown produce and only 7% of them were less willing to buy locally grown produce (Fig. 1).

The mean values mentioned in this paper were based on the available observations after deleting the missing values from the dependent variable (Table 1). On an average, each respondent visited ethnic stores 3.8 times per month to purchase produce (VISIT_TIMES). Each Hispanic respondent spent about US$22.26 per visit on produce (ETH_SPEND). The average distance from residence to grocery store (DISTANCE) was about 13.68 miles. About 28% of the respondents purchased ethnic produce from typical American grocery stores (ETH_BUY_AMER). About 68% of the respondents reported that the store availability (STORE_AVBL_IMP) is very important to them and 40% of them felt that the language attribute (LANG_IMP) is very important when they visit the store.

Furthermore, 62% of them preferred price (PRICE_IMP), 25% of them preferred ethnic stores for packaging (PACKG_NOTIMP) and 37% for freshness (FRESHNESS_BETTER). When the respondents were asked whether they find the Hispanic ethnic outlets to be better than the conventional stores in terms of fruits and vegetables, approximately 45% of them felt that price is better (PRICE_BETTER). While, in the case of packing (PACKG_SAME), 54% of the respondents felt that the packaging of produce was the same in ethnic stores when compared with other conventional stores. In terms of willingness to buy, 56% of the survey respondents were willing to buy organic produce (ORGNIC_MORE_WTB), 47% of them were willing to buy country-of-origin-labeled

produce if available (COOL_MOREWTB) and 55% of the respondents were willing to buy recently introduced produce or new to the market (NEWMRKT _WTB). In terms of influence of the promotional materials, 55% of the respondents were influenced by out-of-store advertisements (OUT_STORE_ADD). The respondents' average years of living at the current location (YEARS_LIVE) was about 13 years. The average number of people per household from survey (HSIZE) was 3.86 persons, whereas the average was 3.5 persons in the 2000 US Census, compared to national average (3) during the same period[27]. The average number of children below the age of 17 years (BELOW17) was 1.43 persons in a family, whereas the census average was about 1.78 children below the age of 18 years in 2000, which consists of one-third of the total US Hispanic population. About 11% of the respondents had education less than 12th grade and 35% of them had high-school education (HSCHOOL). In terms of income, 19% of the survey respondents had income less than $20,000 (INC_LES20), 22% had income between $40,000 and $59,999 (INC_40TO80) and only 8% of them had income between $80,000 and $99,999 (INC_80TO100). No prior assumption was made about the effect of income on an individual consumer's willingness to buy locally grown produce. About 76% of the respondents were female (FEMALES). No prior assumption was made regarding the effect of gender variation on the dependent variables.

Model Estimation Results

Table 2 shows the estimated model marginal effects of the explanatory variables along with their estimated *t*-ratios. The table also shows the estimated values of unrestricted (i.e., full model) and restricted (i.e., slope coefficients are zero) log-likelihood function, Chi-square statistics of model significance, McFadden's R^2 and the model prediction success rate. The Chi-square statistic of overall model significance is 81.80, which is clearly greater than the 95% critical value for this test. Therefore, the model has significant explanatory power. The McFadden's R^2 is 0.12 with 80% prediction of success and the overall model is highly significant (at 0.00). The ordered probit model results in terms of marginal effects and explains the direction of willingness to buy locally grown produce.

According to the model estimation, those who visited an ethnic store more frequently (VISIT_TIMES), those who felt ethnic language attribute (LANG_IMP) is very important at the store to make a purchasing decision, those who viewed packaging as not important (PACKG_NOTIMP), those who were willing to buy organic produce (ORGNCI_MORE_WTOBUY) and country-of-origin-labeled (COOL_WTOBUY) produce, those who were willing to buy produce when recently introduced or new to market (NEWMRKT_MORE_WTOBUY), those who had lived longer at the current location (YEARS_LIVE), those with more children below the 17-year age group (BELOW17) and those with income between $80,000 and $99,000 (INC_80TO100) were more likely/willing to buy locally grown produce. Furthermore, those who thought that the freshness of produce is better in ethnic stores when compared with other conventional stores (FRESHNESS_BETTER), those who viewed packaging of produce to be the same in ethnic stores when compared with other conventional stores (PACKG_SAME), those who were influenced by out-of-store advertisements (OUT_STORE_ADD) and those with bigger household size (HSIZE), and those with income less than $20,000 (INC_LESS20) were less likely to be associated with willingness to buy locally grown produce. However, the model also indicates that variables, such as ethnic produce expenditure, respondents who buy all ethnic produce from typical American grocery stores, ethnic store distance, store availability, price, education, income of US$40,000–60,000 and gender do not have any significant impact on the willingness to buy locally grown ethnic produce.

The marginal effects in Table 2 show how an increase of one unit of the independent variable changes the probability of willingness to buy locally grown ethnic produce when the independent variable is continuous. In case of a binary variable, the marginal effect shows how the probability of willingness to buy locally grown ethnic produce changes if the binary variable switches. For instance, the marginal effect of ORGANIC_MORE_WTOBUY at willingness to buy locally grown produce value Y_1 is 0.1789 (18%), which means that if ORGANIC_MORE_WTOBUY switches to the one who is willing to buy organic produce when compared with those who are not willing to buy, the probability of willing to buy locally grown ethnic produce will change by about 18%. The signs of the marginal effects are potentially ambiguous, except when $Y_i = 0$ or 2, which are unambiguous and opposite to each other (e.g., Greene[28]; Powers and Xie[29]). Taking into account this constraint when discussing the results, the pattern of signs of marginal effects over the willingness to buy locally grown ethnic produce is discussed below.

The marginal effect shows that those who spend more on ethnic fruits and vegetables (ETH_SPEND) are more likely/willing to buy locally grown ethnic produce. Since the magnitude of the marginal effect is not sizeable, the impact of ethnic expenditure is very limited on willingness to buy locally grown produce. Those who think that the language attribute is very important (LANG_IMP) are more likely/willing to buy locally grown produce than those who think otherwise. This is possibly because majority of Hispanics in America are immigrants and/or have spent a relatively short time in America and use English as a second language. Perhaps they prefer produce labels, customer service and advertisements in their native language. Those who think that packaging is not important (PACKG_NOTIMP) are more likely/willing to buy locally grown ethnic produce compared to those who have preference for packaging. Those who prefer organic produce (ORGNCI_MORE_WTOBUY) are more likely/willing to buy locally grown ethnic produce compared to those who think

Table 2. Willingness to buy locally grown fruits and vegetables: ordered probit model estimates.

	Estimated marginal effects and *t*-ratios					
	Willing to buy		Indifferent to buy		Less willing to buy	
Variable	Marginal effects	*t*-ratio	Marginal effects	*t*-ratio	Marginal effects	*t*-ratio
Constant	0.0000		0.0000		0.0000	
VISIT_TIMES	0.0001**	1.9320	−0.0001**	−1.9280	0.0000	−1.472
ETH_SPND	0.0000	−0.5060	0.0000	0.5080	0.0000	0.490
ETH_BUY_AMER	−0.0142	−0.7520	0.0091	0.6600	0.0050	0.236
DISTANCE	0.0011	1.3600	−0.0007	−1.3610	−0.0004	−1.295
STORE_AVBL_IMP	−0.0180	−1.0120	0.0117	0.8510	0.0063	0.313
LANG_IMP	0.0624**	2.2270	−0.0408***	−3.8510	−0.0216	−0.827
PRICE_IMP	−0.0152	−0.8320	0.0098	0.7200	0.0053	0.260
PACKG_NOTIMP	0.0581**	2.1420	−0.0384***	−3.6080	−0.0197	−0.796
FRESHNESS_BETTER	−0.0319*	−1.9120	0.0205	1.4120	0.0114	0.566
PRICE_BETTER	0.0166	0.7390	−0.0107	−0.8570	−0.0058	−0.252
PACKG_SAME	−0.0315**	−1.9640	0.0204	1.4390	0.0110	0.577
ORGNIC_MORE_WTOBUY	0.1789***	4.2090	−0.1103***	−21.4510	−0.0686*	−1.643
COOL_WTOBUY	0.0670**	2.3210	−0.0434***	−4.1340	−0.0236	−0.862
NEWMRKT_MORE_WTOBUY	0.1045***	3.0870	−0.0667***	−7.4440	−0.0378	−1.180
OUT_STORE_ADD	−0.0304*	−1.8690	0.0197	1.3870	0.0107	0.552
YEARS_LIVE	0.0005**	2.3780	−0.0003**	−2.3940	−0.0002*	−1.638
HSIZE	−0.0009**	−2.3510	0.0006**	2.3710	0.0003*	1.627
BELOW17	0.0005**	1.9730	−0.0003**	−1.9860	−0.0002	−1.492
LESS12GRADE	−0.0220	−1.2000	0.0140	0.9810	0.0080	0.369
HSCHOOL	0.0210	0.9200	−0.0137	−1.1120	−0.0073	−0.317
INC_LES20	−0.0485***	−3.0970	0.0305**	1.9720	0.0179	0.872
INC_40TO60	−0.0132	−0.6950	0.0085	0.6160	0.0047	0.219
INC_80TO100	0.0527**	2.0420	−0.0354***	−3.3410	−0.0174	−0.760
FEMALE	−0.0204	−1.1860	0.0133	0.9710	0.0071	0.363
LL function	−292.24					
Restricted LL	−333.14					
Chi-square	81.80					
DF	24					
McFadden R^2	0.12					
Prediction success	80%					

* $\alpha = 0.10$, ** $\alpha = 0.05$, *** $\alpha = 0.01$.

otherwise. Those who are willing to buy country-of-origin-labeled (COOL_WTOBUY) produce are more likely to buy locally grown ethnic produce than those who are not willing to buy COOL products. Those who are willing to buy a recently introduced product (NEWMRKT_WTB) are more likely to buy locally grown ethnic produce than those who are not willing to buy recently introduced products. Those who have lived longer at the current location (YEARS_LIVE) are more likely/willing to buy locally grown ethnic produce compared to those who did not. Those with more children below the 17-years age group (BELOW17) in a household are more likely/willing to buy locally grown ethnic produce compared to those who have fewer children below that age group. Those with an income between $80,000 and $99,000 (INC_80TO100) are more likely/willing to buy locally grown produce compared to those who have an income over $100,000.

The subsequent consumer attributes have a negative impact on willingness to buy locally grown ethnic produce items. The marginal impact shows that those who think that the freshness of produce is better in ethnic stores when compared with other conventional stores (FRESHNESS_BETTER) are less likely/willing to buy locally grown ethnic produce items compare to those who think otherwise. Those who consider packaging of produce to be the same in ethnic stores when compared with other conventional stores (PACKG_SAME) are less likely/willing to buy locally grown ethnic produce items when compared with those who think otherwise. Those who are influenced by out-of-store advertisements (OUT_STORE_ADD) are less likely/willing to buy locally grown ethnic produce items when compared with those who are not influenced by out-of-store advertisements. Those who have a bigger household size (HSIZE) are less likely/willing to buy locally

grown ethnic produce items when compared with those who have a smaller family size. Those who have an income less than $20,000 (INC_LESS20) were less likely to be associated with willingness to buy locally grown produce when compared with those who have an income higher than $100,000.

Summary

According to the survey results, overall, 80% of the respondents were willing to buy locally grown produce, 13% of them were indifferent to buy locally grown produce and only 7% of them were less willing to buy locally grown produce. The high positive percentage indicates the intensity of consumers' interest toward buying locally grown produce. As the model results indicate, those who prefer ethnic language at a store were positively associated with willingness to buy locally grown produce. The results also indicated that those who felt that packaging is not important were positively related with willingness to buy locally grown produce. Those who were willing to buy organic produce were positively associated with willingness to buy locally grown produce. As the results indicate, those who prefer to buy when country of origin is labeled were positively associated with willingness to buy locally grown produce. Respondents who were willing to buy produce when recently introduced or new to market and those with income of between $80,000 and $99,000 were also positively associated with willingness to buy locally grown produce.

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What does 'local' mean in the grocery store? Multiplicity in food retailers' perspectives on sourcing and marketing local foods

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Abstract

Local food systems are comprised of networks of actors that work to ensure the sustainability of food supplies within communities. While local food has typically been promoted through direct marketing strategies such as farmers' markets and community-supported agriculture (CSA), retail stores are increasingly carrying and marketing local foods in response to consumer demand and market potential. Given the frequency with which consumers shop at grocery stores, as well as the portion of consumers' food purchases made at these locations, these stores may play a significant role in the success of local agriculture and the shaping of ideology about what is 'local'. We conducted 27 semi-structured interviews with representatives of food retailers known to source and market local foods in the four major urban centers of Oregon's Willamette Valley. Our results reveal that grocers' perceptions of local food vary significantly from one another. Additionally, our results differed in comparison to the published literature on consumers' and producers' ideas of what constitutes local. Food retailers identified varying distances (frequently a region including several states) that they consider local, as well as diverse reasons for choosing to source and market local foods (most commonly supporting the local economy). Some trends in the variation of responses relate to how the size and form of ownership of the grocery stores influence the level at which decisions are made. These wide-ranging perceptions outline many of the realities of the local food movement, as well as opportunities for change.

Key words: local food system, Willamette Valley, bioregion, grocers, food retailers

Introduction

Local or community food systems are complex networks of relationships between actors including producers, distributors, retailers and consumers grounded in a particular place. These systems are the unit of measure by which participants in local food movements are working to increase food security and ensure the economic, ecological and social sustainability of communities. We define the local food movement by the large number of actors such as locavore groups, farm-to-school programs and progressive restaurants that view eating as a political act[1]. Although local food systems maintain the health of a particular place as a central value, this does not necessarily preclude trade with other communities[2]. Members of a local food system may maintain relationships that extend beyond the spatial parameters of what they define as 'local', while creating and strengthening new relationships within their community. In examining the significance of local food systems and assessing their feasibility, it is important to look critically at each level of the food supply chain's influences and motivations. Allen[3] notes that doing so allows the members to work toward long-term individual empowerment by understanding the relationships that affect access to any part of the local food system. The food security of a community may be more effectively increased if all actors understand the relationships that shape their food system. One central element which influences these relationships is how 'local' is defined.

A number of different definitions for local have been used or recorded by researchers assessing local food systems—most informed by political or geographic boundaries[4–10]. Among the more widely circulated and popular defining parameters is the concept of food miles, which has

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been suggested for policy recommendations[11,12]. Born and Purcell[13], Coley et al.[14] and Edwards-Jones et al.[15] have found food miles to be a useful concept for garnering public attention, but recommend more nuanced case studies be used in individual local food systems when determining the relative effectiveness of different concepts of local food, given the inaccuracy of measuring sustainability with a single distance[13].

Recent studies of local food systems have identified and described many of the key components of these systems. Hinrichs[16] reviewed the values that shape direct agricultural markets between producers and consumers and how these may create tension between food-related concepts of community and commodity. Zepeda and Leviten-Reid[17] and Selfa and Qazi[18] have conducted case study research analyzing the perspectives of consumers and producers in local food systems. Others have worked to test and clarify local food movement claims, as well as the definitions of 'local' used by participants in direct agricultural markets and other forms of local food distribution[13–15,19]. These researchers have found a wide range of positive and negative associations made with local food. Differing perspectives on what constitutes local lead to the conclusion that, if local is also to reflect ideas of social justice and ecological sustainability, its definition cannot be based on scale alone[19–21]. What the body of literature on local food systems indicates is that 'local' holds connotations for many people beyond the geographic distance that the food has traveled. The local food system definitions and development must consider the agendas, interpersonal connections and emotional responses of participants at all levels[16,22–24]. We believe that transparency in the characteristics of a local food system is important (particularly in retail marketing) as consumer demand for local food grows.

Increasingly, local foods are not only marketed through farmers' markets and community-supported agriculture (CSA) but also in large and small grocers from cooperatives to supermarkets[25–28]. Demand for local food has driven this trend, and attitudes toward local food have been documented as positive, with the majority of consumers willing to pay a premium for it based on the proximity marketing alone[4,5,29]. Despite the relatively large part that food retailers play in shaping food decisions, their perspectives have not yet been included in an analysis of local food definitions, nor has their role been studied as thoroughly as direct market interactions. This could be a product of what Hinrichs[22] describes as a binary of global versus local when framing food system localization. This binary excludes food retailers on the basis of a lack of interactions between consumer and producer, as well as the belief that their larger scales and global influences are intrinsically negative[16,18]. We feel that understanding such retailers' perspectives on local foods is important for several reasons:

- First, most consumers will purchase a majority of their food from food retailers[18,22,29]. Learning how food retailers such as hyperstores, supermarkets and greengrocers define and market local food has great significance in terms of transaction volume, whereas direct agricultural markets are important for understanding the personal connections that exist between the producer and consumer[30,31].
- Second, the inclusion of large distributors as actors in local food movements may work to reconcile weaknesses raised by the economies of scale, particularly transportation and food availability[3,4,13].
- Third, Norberg-Hodge[32] suggests that it is helpful to consider institutions that are able to promote local food on a large scale (e.g., regional and national retailers that source locally). This is because small-scale efforts to develop local food systems can be isolated and scattered, while food retailers often have the resources necessary to promote these efforts to a broader audience and thus have a more significant impact. Food retailer perspectives on local food systems can inform consumer definitions, and guide them toward locally sourced options.
- Fourth, Macias[20] calls for broader social inclusion in what is referred to as 'local food projects', something more feasible through large food retailers who sell local foods at prices accessible to a greater socio-economic range of consumers.
- Fifth, the influence that such retailers have may lessen the difficulties of realizing social justice and equity on a local scale[33] by making local food resources available to a greater number of community members[21].

The perspectives of food retailers on local food systems merit further study, especially considering the relative volume of their potential contributions to local food movements.

As the aforementioned research suggests (and Feenstra[2] established), there is a need for local food system research that goes beyond simple spatial parameters such as scale, and provides strategies to strengthen these systems. These strategies include researching local food systems themselves and conducting studies intended to reveal the barriers and opportunities for connecting consumers with local food resources. In response to the need for research on the role of retailers in local food systems, and to examine these systems beyond scale alone, we conducted surveys with food retailers in Oregon's Willamette Valley. Feenstra[2] notes that marketing studies such as ours can be 'helpful in understanding food distribution dynamics, barriers, and opportunities within a specific region' descriptive of 'the reality of a particular food system, its participants, the control points, and the possible changes' (p. 33). Categorizing Feenstra's[2] suggestions of the possible contributions of this type of research under four headings—*realities*, *participants*, *control points* and *possible changes*—we will discuss our results, referring to differences and similarities with previous research. Our research describes the way that food retailers—critical actors in the middle of the typical food supply chain—market relationships may shape local food systems.

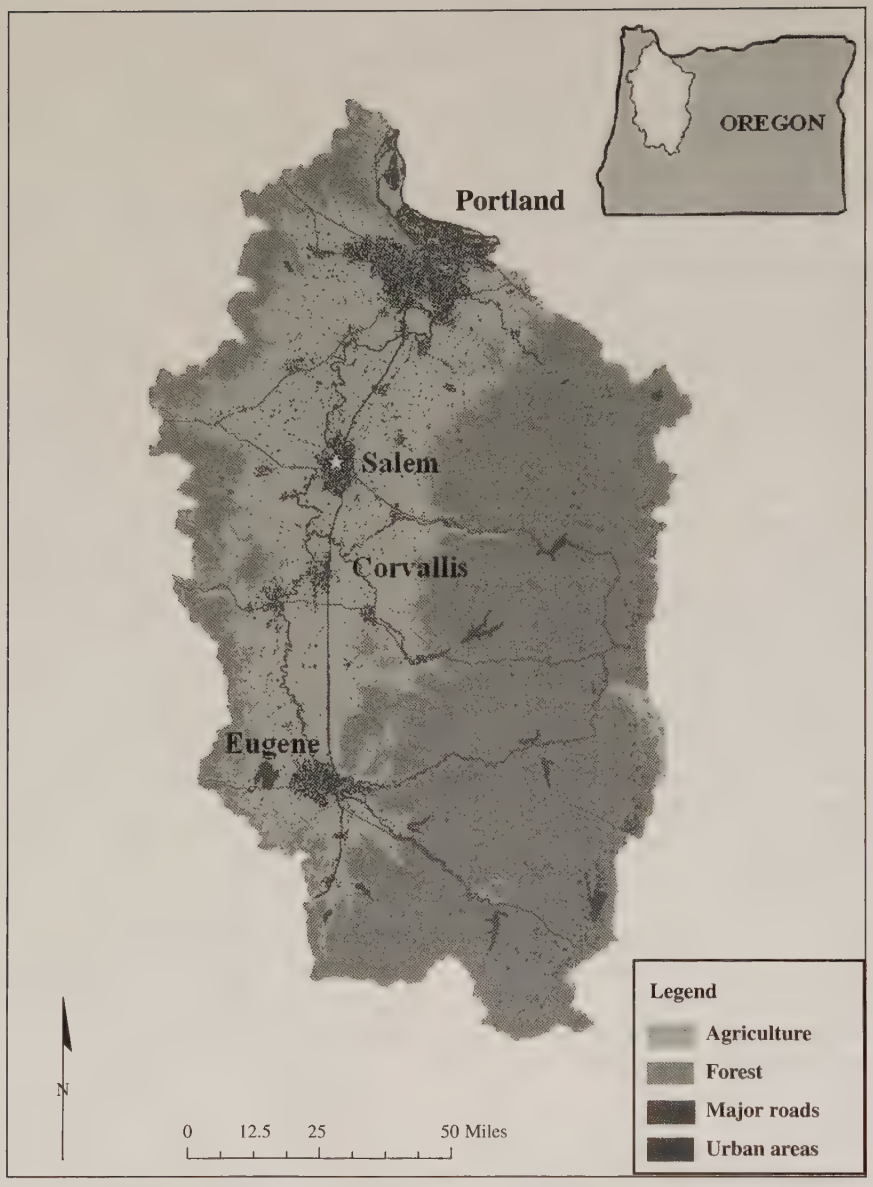

Figure 1. Willamette Valley watershed delimitated by the Coast Range and Cascade Mountains to the west and east, respectively, the Columbia River to the north and the Umpqua watershed in the south. Map created using data from the Oregon Geospatial Data Clearinghouse[36] and the Pacific Northwest Ecosystem Research Consortium[37].

Methods

An important component of studying local food systems is establishing the geographic designation of the study area. Our research was conducted in Oregon's Willamette Valley bioregion (we use Berg and Dasmann's[34] definition of a bioregion as both a *geographical terrain* and a *terrain of consciousness*). We chose the Willamette Valley (WV) bioregion, based on the Willamette River watershed (see Fig. 1), as our study area due to several complementary attributes: a rich agricultural history and continuing production, a cultural identity based on food in the region, the ability to identify it as a bioregion and the presence of local food marketing. We spatially delineated the WV local food system by watershed boundaries. Within the boundaries, we interviewed retailers that market foods as local or are known for sourcing locally (i.e., 'local food retailers'). We conducted surveys in four major urban centers in the WV: Portland, Salem, Corvallis and Eugene. These cities are the most populous of the WV and represent relatively diverse socio-economic profiles and cultural identities[35]. The full range of local food retailers in the WV may not be equally presented in this research as the interviewees were all within large urban areas, and their perspectives may differ from those of rural food retailers. Although it is possible that we did not completely catalog the local food retailers, 93% of those that we did completed the majority of the interview.

Using government and public Internet listings, locavore listservs, published research conducted in the WV and

interviews, we compiled a list of 97 food retailer locations that source and market local foods regionally. The food retailers that we interviewed generally fell within the parameters of three of the four categories outlined by Guptill and Wilkins[25]:

- Hyperstore—a retailer with at least 100,000 square feet and $12 million in annual sales. Typically a retail chain selling diverse goods and services in addition to food.
- Conventional supermarket—a retailer with less than $12 million in annual sales that does not offer extensive services. Conventional supermarkets are similar to hyperstores in that they feature products from major food manufacturers.
- Green grocery store—a retailer that typically carries specialty, natural and organic food with some products from major conventional food manufacturers. These can be cooperatives, proprietorships, partnerships or corporations.
- Discount grocery store—a retailer that stocks a limited number of items featuring low prices based on offerings from overstocks and other traditionally inexpensive foods. None of the stores surveyed met the requirements of this category.

Classifying grocery stores was approximated, as some did not possess all of the defining characters.

We conducted 27 interviews during June and July 2009. The number of actual interviews was lower than the total number of retailers carrying local foods in the four urban centers. This discrepancy resulted from 12 retailers having a single distribution center or adhering to a chain policy, which dictated store purchasing and labeling practices at 82 individual stores. The remaining 15 interviews represented one location each. Interviews were conducted with every representative local food retailer in each of the urban centers. Please see Table 1 for the total of individual WV grocery stores in Guptill and Wilkins[25] categories and the number of interviews conducted for each.

Although we requested interviews in person with all food retailers, due to the time constraints on the part of some, we were only able to conduct 20 of the 27 interviews. The five phone interviews and two e-mail exchanges were not as effective as the in-person interviews, resulting in fewer extra comments and observations. Anecdotal contributions from some interviewees were valuable for understanding the unique perspectives of food retailers given that little prior research had been conducted with them.

We sought to interview those who were responsible for policy and purchasing decisions. A majority of the time, we were able to interview the owner or manager of single stores, or the person responsible for coordinating decisions for a chain store. The interviews were semi-structured and lasted between 30 min and 1 h. For open-ended questions, we categorized answers and recorded comments during the interviews. The survey questions were structured around three main themes: how local food is defined and marketed, motivations for carrying local food and regulating definitions for local food. During the interviews, questions regarding local food deferred to the definition of 'local' provided by each interviewee. Each theme included open-ended and categorical questions. Survey question development was informed by a diversity of published literature, particularly research conducted by Forsman and Paananen[38] on the opportunities and challenges of marketing local foods.

In order to verify and compare interview responses regarding the marketing of local foods, we studied the labeling and signage used in store promotions of these items. We recorded the types of signs present and the information displayed on them, as well as what types of foods were labeled 'local' and how this information was communicated. We recorded observations at each of the independent stores interviewed, and at one location each of the chain store distribution centers.

Table 1. Number of food retailers and interviews conducted in the major urban areas of the Willamette Valley (Portland, Salem, Corvallis and Eugene).

Store type*	Number of locations	Number of interviews
Hyperstores		
Supercenter	18	2
Warehouse-wholesale club	6	1
Total number of hyperstores	**24**	**3**
Conventional supermarkets		
Conventional chain supermarket	31	1
Conventional independent supermarkets	8	4
Total number of supermarkets	**39**	**5**
'Green' grocery stores		
Chain green grocery	13	3
Independent green grocery	21	16
Total number of 'Green' grocery stores	**34**	**19**
Total number	**97**	**27**

* Store classifications based on Guptill and Wilkins[25].

Findings

Based on estimates provided by interviewees the following results account for values that may affect more than 190,000 weekly grocery transactions in the WV. Results are derived from questions that are the key to understanding retailers' roles in local food systems: *How is local defined? Why are local foods carried? What products are local? How are those products labeled?*

Given the small number of hyperstores and supermarkets compared to 'green' grocery stores, it was difficult to make comparisons between groups; thus, the majority of the data is presented in aggregate. We have included respondent comments for perspective on the role of retailers, as well as for insights unique to particular retailers or retail categories

which may foreshadow future roles of these key actors in local food systems.

How is local defined?

We found that the parameters food retailers use to define 'local' differ significantly from those of consumers and producers. This reflects Harper[39] who noted that despite research critical of the claims and definitions of local, local foods in supermarkets are often defined solely by scale and proximity. We also found that definitions of local vary widely between retailers and that many of the definitions used are neither strict nor tightly regulated but based on a general idea of where local food is coming from. Compounding the confusion of different stores having different geographic distances for local, only 20% publicly display their definition of local.

Retailers' stated that their definitions of local are informed by a number of sources and responded that they are strongly influenced by the availability of products and by customer values. Other retailers and distributors were described as somewhat influential. They described being influenced very little by popular literature and market research. Seven retailers had received input from consumers on how they feel local should be defined (via comment cards and conversations). Six respondents indicated that they have formed their definition of local based on what is the easiest for them to use, while six others stated that their definition was based on the evaluation of the availability of food locally. Hyperstore and conventional supermarket respondents were generally more constrained in the local definition development by their market and corporate distribution structures. Three retailers adopted definitions already in common use and easily understood by their customers.

Although food retailers ranked sources such as media coverage of the locavore movement as having little influence on their selection of a parameter for establishing what local foods are, we found their definitions to be remarkably similar. Based on popular literature (such as Pollan[40], Kingsolver et al.[41] Smith and MacKinnon[11]), studies of local food systems[7,8,14,15,29,42] and previous studies of local food definitions[9,17,18,43], we expected to find retailers marketing local food in terms of political boundaries such as county or state borders, or geometric boundaries such as driving distance or radius. We found this to be true, with variability in the scales of the parameters used.

The parameters for determining local food which WV retailers reported using included unidirectional distances, geographic regions, personal connections and political boundaries. Of the six that used distance, the radii were between 100 and 200 miles. An equal number of food retailers used regions such as the Pacific Northwest or the WV to visualize local food, usually in conjunction with another parameter such as political boundaries. Two retailers described local food in terms of the producers whom they knew personally and had built a relationship with during the history of the business, which roughly corresponded to a 100-mile radius. Political boundaries were most commonly used to delineate local, with the single most common parameter a combination of more than one state ($n = 11$). Other political boundaries included Oregon only ($n = 3$), counties ($n = 2$) and city ($n = 1$). For 42% of the retailers, however, location is not the only defining character of local food. Hyperstores and conventional stores have quality and safety requirements for all products that local food must also meet, green grocers often focus on the methods used to produce the food, as well as on farm size, local ownership and local operation. Some retailers also consider the nature of the product itself when designating foods as local.

Foods processed within the designated local area, but not necessarily grown there, were considered local by 70% of the respondents. The majority who considered these goods local stated that this was because these processing centers contributed to the local economy through job creation. Others described such an expanded definition of local as '*a slippery slope that we don't want to get caught up in*', and expressed concern that such standards would harm their reputation. Thirty-three percent of respondents considered food produced inside their designated local boundaries, but processed outside of the area to be local food, largely on the basis of maintaining support for local producers who do not have access to local processors. Some green grocers gave additional consideration to the production methods that producers use, and in some cases will not carry a local food unless it is organic, transitioning to organic, or otherwise mindful of detrimental environmental inputs. None of the retailers considered the origins of ingredients (as is commonly done with wine labeling when the majority of the grapes must be sourced from a particular area to be identified with that region).

Why are local foods carried?

We found that in response to an open-ended query regarding the reasoning for carrying local foods, the most common response was to support the local economy. Other common responses, in order of decreasing popularity included environmental concerns, increased product quality and meeting the increasing demand for local food. There were several reasons mentioned by relatively fewer retailers that had importance in describing their role in local food systems. One retailer noted that in order to truly support the local economy, he has to consider whether or not the wealth is shared equitably between producers and distributors. For some retailers, equality is fostered through farm-direct purchasing; for example, purchasing from '*a woman with a bumper zucchini crop from her garden down the street*', as well as from large-scale farms. Personal beliefs also motivate food retailers. Several responded that sourcing from local farms is simply the right thing to do, while

others felt that eating within one's bioregion is intrinsically healthier and better for their customers.

Representatives of large- to small-sized retailers commented that sourcing locally is integral to their identity, something often visible in their mission. Many representatives of large retail stores indicated that sourcing locally also comes from national marketing initiatives that are largely consumer driven. Several small retailers stated that they were involved in regional organizations such as the Willamette Farm and Food Coalition[44] (http://lanefood.org) which provide rationale for buying local food and often reference community sustainability. Respondents also frequently provided literature to accompany their responses, citing as many as 10 separate reasons for buying local foods.

Two-thirds of food retailers interviewed confirmed that their reasons for supplying local food have changed over time. The widely observed increase in demand has made carrying local food a customer-driven practice in many stores. Indirectly, consumers have changed retailers' reasons for carrying local food as they have become more aware of the environmental issues related to food production, the impacts of rising energy prices and the influence of the recent economic conditions.

In order to strengthen the previous line of open-ended questioning regarding reasons for carrying local food, we asked interviewees to rank and categorize their strategies for sourcing locally. They based their rankings on a scale of one to four with one being 'very important', two being 'important', three being 'somewhat important' and four being 'not at all'. Respondents generally indicated more than one significant reason for sourcing local foods. Factors considered very important for sourcing local food included: food quality (78% of respondents); environmental concerns, social concerns and community involvement (approximately 65% of interviewees for each response); economic reasons (58% of respondents); and 35% included safety as very important.

When asked to state what the most important consideration was for sourcing local food, eight respondents stated food safety. They noted that this was largely a reaction to an increasing number of food safety scares and recalls, which requires them to always consider safety, regardless of whether the food is local or not. Food quality or economics were each selected as the most important reasons by six retailers. Four respondents ranked social reasons as their number one concern. One respondent felt environmental concern was the most important. The reported rankings of reasons for carrying local food also reflected some differences in interpretations of the broad categories. Social and economic reasons were often viewed as interchangeable, with several retailers considering themselves '*small business incubators*', making contributions to their local economy through social relationships with small-scale producers. Smaller retailers indicated that the size of their businesses made them better suited to stocking local food produced on a small scale.

The values and reasons that motivate retailers to carry local foods are also affected by business realities. These realities include the relationships each form, as well as the costs and benefits each must weigh. Seventy-five percent of food retailers surveyed stated that their reasons for carrying local food are communicated to the customer via marketing forms including informational materials such as pamphlets and advertisements. Many invite producers to demonstrate products at their stores, providing the face-to-face relationship that is a primary driver of direct-market agriculture and discussed in Selfa and Qazi[18] and Allen[29]. Some choose not to provide informative marketing such as display signs that mention the benefits of local food, indicating they preferred customers with their own individual perceptions and definitions of local food to make purchasing decisions based on available information (e.g., product origin).

Interviewees also stated that they tap into direct-market tools in several ways to find sources for local food. Accessing local WV food resources such as directories of CSAs and geographically proximate farms, farmers' markets and the Food Innovation Center in Portland[45] (http://fic.oregonstate.edu/), has allowed retailers of all types to develop relationships with farmers and pass the benefits of those relationships on to customers. This is evidenced by the fact that 92% of local food retailers described actively pursuing or encouraging local producers to sell to them. Several green grocers stated that they charge smaller margins for local products, help farmers to transition to organic methods, act to support the development of small businesses, carrying unique items on the basis of local origin and strive to develop long-standing relationships with producers. Conventional supermarkets and hyperstores similarly pursue local producers and strong mutually beneficial relationships, but their sourcing is often restricted by their volume requirement.

Once relationships have been formed between producers and retailers, contractual obligations are rarely established. Agreements are most often made with handshakes since '*sometimes Mother Nature screws* [*producers*]', and neither party wants to be held liable to unpredictable yields. Interviewees stated that commodity market conditions are the biggest obstacle to contracting, as prices are increasingly volatile, causing retailers and distributors to change their sources often. Larger stores, in particular, set standards for quality, insurance, liability and price stability.

Food retailers indicated that they face a variety of challenges unique to carrying local foods. Retailers of all types have frequent difficulties with local product availability. This problem contributes to their sentiment that '*we've spoiled the consumer*' and given consumers the expectation that most products can be locally sourced. Retailers regularly stated that despite consumer demand's role as an important reason for supplying local food, consumers often exhibit a poor understanding of their local food systems. Hyperstore managers, conventional retail buyers and green grocery owners all mentioned

dilemmas such as reconciling the popularity of items such as bananas with sourcing locally and responding to customer requests for items such as local tomatoes in winter. In addition to importing produce, large food retailers expressed obstacles for working with all scales of farms, local and non-local, in order to stay well stocked with products that are in high demand. The consistency and quality of local foods are in some cases obstacles to grocers who must provide the customer with a product that meets many different expectations. Interviewees indicated that one of the most difficult expectations to meet is the cost of local food, as some customers may be less willing than others to pay a premium for it. One retailer noted that the commodity market has significantly decreased the accountability of producers and made labeling local foods difficult, as their origins may change on a weekly basis. Frequent changes in the source of a product make it difficult for retailers to maintain consistent place-based marketing. Barcodes and packaging are difficulties for some small-scale producers and processors, but many respondents indicated that they work with farmers to help them to resolve these issues.

The various changes made by different types of stores in order to carry local foods reflect the diversity of their customer bases and reasons for carrying local foods. Most commonly, sourcing and labeling local foods necessitates a greater time commitment, especially since retailers may have to place orders directly to several local farmers as opposed to placing a single order to a distributor that may or may not be sourcing locally. Some stores have sacrificed revenue or product selection due to their commitment to local foods. Hyperstores and conventional markets must cater to customers who consider price to be their top priority, especially in light of the recent economic downturn. Despite the importance of price, they have noted that customers will pay a premium for local foods even if they are of lower quality. Several of the hyperstores and some conventional markets surveyed stated that they receive the majority of their local food through existing distribution mechanisms and that their only recent change has been to promote and label the food as local. This might have been influenced by the federally mandated Country of Origin Labeling, which was put fully into effect on March 16, 2009 and requires standard labels on produce[46]. Now that these stores must track and label the national origin of their products, they have gone one extra step and labeled foods as local if they come from a relatively close area.

Despite the difficulties and changes necessary in order to carry and market local foods, all retailer categories indicated that they have benefited from doing so in a variety of ways. Interviewees felt that when demands for local food are met, customers are more satisfied with their products, and they have a sense of having contributed to the community. Retailers stated that the increased quality of products they offer has improved their public image and their revenue.

What products are local?

Reflecting ongoing increases in awareness of the local food movement, many retailers we interviewed only recently started local food programs (some the very week we called to schedule their interviews). As a result, their estimates for the annual volume of local foods carried are largely based on personal perceptions as opposed to records.

Although we asked interviewees to estimate their total volume of locally sourced foods throughout the year, some stores were either not tracking this information, or did not carry local foods of any type besides fruits and vegetables. We categorized answers for grains, meat and beans, dairy, fruits, vegetables, prepared foods, other products and oils as $<5\%$, 6–25%, 26–50%, 51–75%, 76–100% or N/A. The quantities reported indicate specific difficulties that food retailers have had with local product availability and origin verification. Local grains, for example, were most often described as coming entirely from *Bob's Red Mill*, based in Milwaukie, OR (within the WV watershed) (median value for all grocers of 6–25%). Respondents clearly understood that the grains were milled there, while assuming that '... *he's being pretty good about* [*sourcing locally*]' or '... *running an honest operation*'. Other local processors and cooperatives were recognized by name for dairy (median 51–75%) and meats (median 51–75%), but it was noted that a lack of large local processors complicates accounting for food miles since locally raised livestock may be shipped long distances for processing. On an average, interviewees responded that 26–50% of both fruits and vegetables were sourced locally, but that this amount varies significantly between seasons. A median of 6–25% of the volume of prepared foods such as deli items and packaged goods, as well as other products such as personal care or alcoholic beverages were local. Finally, less than 5% of all cooking oils were local. We also requested sales data for each of the categories of local foods carried, but only four stores were able to provide estimates.

Similar non-local products were carried alongside local products at 71% of the locations we visited. Of the retailers that did this; 13 indicated it was necessary in order to increase the selection, nine justified carrying alternatives to have a lower-priced option, and one did so if the products were significantly different. One hyperstore carried non-local products in order to prevent in-store shortages, as local foods may be from smaller producers and consumers are more likely to quickly purchase their entire stock.

How are local products labeled?

The differences that we observed in labeling of 'local' by food retailers may be a source of confusion for their customers. Of the retailers we interviewed (all of which are known to source locally), 87.5% label foods as local. Of those that label local foods, four simply use the word 'local', 16 indicate the political place of origin (i.e., Oregon), two indicate the region of origin (e.g., Pacific

Northwest) and two consistently name the farm of origin. The names of the farms are in some cases accompanied by information regarding the ownership and practices of the farm. Label format was most often computer-generated signage with hand-written text notations. Several other forms of signage were used to identify local foods including maps of the local area or of local farms.

Respondents perceived labeling as being important to the customer, with 48% having received feedback with regard to their local labeling. Although the median duration of the use of labeling was less than 5 years, with many grocers having initiated a local labeling program in the past year, some stores have sourced and labeled local foods for more than 25 years. Maintaining signage for products in general, and increasingly for local foods, was identified by several grocers as a necessary but difficult task. One interviewee went so far as to complain that the goal is to '*sell a product, not a sign*'. Another complication involving the data on signage and the signs themselves was that employees who had little part in maintaining signage were sometimes responsible for providing the information. As a result, they might perceive the clarity of the labeling differently than either the customer or the sign creator (who may be able to give more accurate answers concerning the signage). Lastly, we noted discrepancies between signage for local items and the products themselves.

Defining local as a bioregion

In order to determine the feasibility of using the WV bioregion as a common delineation for local food, we asked interviewees a series of 'yes' or 'no' questions regarding local food regulation. Eighty-six percent of respondents agreed that retailers should display how they define local food to customers, with 48% indicating that retailers should have strict definitions of what constitutes local. While 57% agreed that there should be a national definition for local food, only 33% responded that all retailers in the WV should use the same specific regional definition of local food. The disparity in the percentage of respondents supporting a national definition versus a regional definition highlights operational differences between retailers that rely on central distribution centers and those that do not. For the former, a WV-specific definition of local would be problematic. In such operations, a single warehouse may be distributing identical locally designated foods to stores within the region as well as to other stores outside the labeling area. In response to questions about legislating what constitutes local, food retailers were quick to mention the challenges of using overly specific criteria for defining local food. They stated that using general guidelines to define local food is quicker and easier for them, and expressed concern that having strict criteria would necessitate more time than they have.

Retailers interviewed recognized the benefits of clear, publicly displayed definitions of local. Given the diverse decisions a consumer must make when purchasing food, a clear definition of local may be helpful. Close attention to the concept may also keep the local area from becoming too large and diluted. With regard to recent increases in the regulation of local food, respondents generally indicated that increased regulation is neither desirable nor feasible, and may dissuade smaller stores within the WV from labeling local foods with their origins. For some retailers, place of origin is not the most important factor when making choices, and so labeling local foods in this manner is not one of their main priorities. Other interviewees indicated that varying perceptions of local held by different people in different places would make using a single definition difficult. Interviewees also recognized benefits to regulating local food. Several noted that a common definition of local would generate input from all scales of the food retail industry, including those who feel that local food should not be defined solely by scale or place. One retailer observed that in order to be effective, local food regulations would also need to be federal policies applicable to large retailers that operate in more than one state.

When presented with the WV bioregion as a possible definition of local, 11 retailers felt that the WV was too restrictive; eight felt it was suitable; three felt that it was too inclusive and five felt that the WV roughly fits the definition they use already. The two most commonly expressed concerns about using a bioregion to define local were the difficulties of being situated near the border of the bioregion and the limited availability of foods within one region. Both of these concerns were felt by seven retailers each. Four retailers mentioned that the WV bioregion as a designated local food area was unclear and too small. Two observed that the region might mean different things depending on where it is used within the WV. One retailer mentioned that transportation systems should be considered when proposing a definition. Ten retailers responded that the bioregion provided a better sense of place than the definition they currently used, and six felt that it fostered a better connection with local food. Two felt that it was a clear definition, and one felt that it would make it easier to select producers. Although the relatively small area of the WV was generally perceived as a problem, one interviewee observed that emphasis on a smaller area would reduce transportation costs.

Discussion

Our finds reflect what Feenstra[2] suggested the contributions of marketing studies on local food systems would be. We now discuss the *realities* of the WV food system, its *participants*, *control points* or balances of power and *changes* that may be made.

Realities

Food retailer perspectives of local foods available within the WV are unique and are invaluable for understanding

production and distribution within this local food system. What retailers choose and are able to stock represents a pivotal point between the supply of producers and the demand of consumers. When describing the realities of the local food system in the WV they highlight concerns with supply and fair pricing for producers and consumers, as well as the benefits of local food in terms of quality and safety.

Allen et al.[33] described short supply chains as characteristic of local food system development, and while many WV retailers are purchasing directly from producers, this is not possible in some cases. We found that large hyperstores, conventional supermarkets and some green grocers are organized around distribution centers that allow for efficient distribution of local foods. This reflects the overall trend of centralization and vertical integration that can be seen in food and beverage corporations[47] and the retail sector as well[48]. Despite these trends, some retailers are able to work directly with producers to show consumers the social relations and environmental practices that may be hidden in the commodity market[33]. Examples include displaying information about farms, or providing opportunities for in-store demonstrations.

Within the WV local food system, social and economic equity (a component of the local food movement which transcends geographic proximity) is being addressed by retailers mainly through consumer access. One key difference between stores and other direct market elements such as CSAs or farmers' markets is access. While farmers' markets are usually open on a single day of the week on a basis which is often seasonal, and CSAs require upfront investment and are also seasonal, stores may be open up to 24 h a day, 365 days a year. Increased temporal access may not only reduce the face-to-face interactions between producers and consumers, which is an important part of local foods[5], but it may also increase access to local food across socio-economic gradients, as food retailers pass savings from economies of scale directly to consumers. Interviewees indicated that prices of local foods are a particularly important consideration for increasing access to them. In Iowa, Pirog and McCann[49] found that, for some commodities, a lack of significant differences between prices of local foods sold at farmers markets and supermarkets exists. While food retailers may believe that they are able to provide cheaper local foods, their prices may actually be comparable to other forms of direct agricultural marketing. We recommend that further research test this claim.

Although some retailers are able to provide inexpensive access to local food, others have found that their customers are willing to pay a premium for it. This is indicative of the conflict between encouraging consumers to treat food less like a commodity and pay the true price of food production, and making food such as organic or fair-trade-certified products available to consumers who must make difficult economic decisions. One retailer in a neighborhood inhabited by residents of mixed and changing socio-economic backgrounds expressed difficulties in trying to meet and resolve competing cost, quality, nutrition and cultural needs. Our results suggest that despite these challenges, making local foods available can be beneficial to all actors involved in a local food system.

A positive reality for food retailers and consumers in the WV is that the products that local producers supply are generally of higher quality. As one interviewee noted, local foods may be grown and harvested for overall quality rather than suitability for transportation. Retailers reported that customers strongly associate local foods with higher quality, an association that has been confirmed across socio-economic profiles[5]. Definitions of quality may vary between individual stores. For some, higher quality primarily meant higher nutrition, for others freshness, and still others felt quality was connected to a particular food or variety of produce that is not grown in other locations (e.g., Walla Walla onions).

Another important reality and continuous challenge for food retailers to address is food safety. Pirog and Rasmussen[50] found that consumers perceive their local or regional food systems to be safer than the US food system as a whole, presenting a marketing opportunity for food retailers to capitalize on. In our study area, one respondent noted that providing safe food is just as important as providing enough food. Most retailers expressed frustration with recalls on contaminated food, a problem that they have little control over which may personally affect a consumer. They selected safety more frequently than any other reason for providing local foods, yet safety was least commonly described as 'very important' (see the results above for '*Why are local foods carried?*'). Many grocers did not feel that local food was necessarily safer, but that safety is their top concern when providing any food and that they must apply such concern to local foods.

A reality relating to social equity of local food systems that was not consciously addressed by any of the respondents was that of farm labor. These findings are similar to those of Macias[20]. One interviewee questioned whether or not people really consider social issues when buying food. Hyperstore representatives agreed that price was still the primary consideration for their respective customers. This illustrates Allen's[29] point that social issues have not typically been effectively addressed by alternative agrifood initiatives.

We found that WV retailers tend to understand the environmental impact of local food distribution, another reality of local food systems in terms of food miles. This understanding is an oversimplification of agricultural production and distribution systems. Crops are often difficult to track on the commodity market, a difficulty which is compounded when the inputs required in producing packaged foods are considered[13–15]. As a result, carbon footprints and food miles may not reflect the true global or local environmental impact of a food retailer carrying a certain product.

Creating a shared sense of place for local food production is an important step to developing a local food

system. The reality is that whether intentional or not, for some empowered consumers retailers have to develop a sense of place for the origins of their foods. One way that this empowerment occurs is through the use of local food displays that often accompany local-labeled foods. These displays frequently include maps of the area that is considered local, and sometimes mention places of origin at different scales on the labels. Further establishment of a sense of place can come from the pictures of farmers sometimes included in the displays, as well as from farmer-run store tastings.

Participants

Feenstra[2] has suggested that studies like this can better connect researchers with participants in the local food system of a specific region. Where the realities and control points of a local food system describe the relationships between actors, we find insights into their identities. These insights are particularly important due to the fact that retailers provide the majority of food in the US, despite being poorly represented in the literature on local food systems. Our research suggests that their perceived roles and identities as participants indicate an increasing understanding of the importance of local food systems. This understanding is illustrated by the way food retailers define local, by the structure of the company, as well as by the values and motivations driving management decisions.

The criteria that food retailers use for defining local food, particularly geographic distances (see the results above for *How is local defined*?), say much about their position within the local food system. Typically WV food retailers defined local as extending not more than 400 miles from the point of purchase. This definition is similar to that used by the US Congress in the Food, Conservation, and Energy act of 2008[51]. However, consumers in the Western US are most likely to consider local food as that which is grown 100 miles or less from the point of purchase[50]. This illustrates a contradiction in how local is viewed by different actors in local food systems. For example, a store 400 miles from a customer would not likely be considered local, but its food might be considered local by a retailer. One respondent observed that customers are increasingly becoming aware that food comes from farms as opposed to stores, but often overlook the distance food must travel to get from those farms to those stores. It is important to remember that multiple definitions were used to define local, including the WV itself. Generally speaking, smaller retailers used smaller spatial boundaries for defining local, and note this as being an advantage to their store over larger retailers when relating to customers. Food retailers need to effectively communicate demand for local food to producers and supply effectively to consumers. The latter has proven difficult when consumers do not understand their local food system's realities. Respondents described feeling responsible for supplying a complete diet to their customers, but felt that the agricultural production potential and current land-use patterns in the WV make this impossible to do by sourcing locally.

Unlike Guptill and Wilkins[25], we found that different practices (e.g., definitions of local) can be correlated to store structure. Larger chains that ship products from distribution centers to several stores used broader spatial definitions of local to facilitate meeting higher demands, while smaller stores often used more proximate definitions inclusive of the producers they work with directly. This difference in operational structure was evident in the relationships that larger retailers form with producers, as they may have national guidelines that local producers must conform to. This reflects the multiplicity of ways that food retailers identify themselves as a participant in local food systems. The various perceptions of local have been difficult for retailers to reconcile when establishing their own definitions of local. As many food retailers observed, finding a definition that will satisfy all customers seems impossible. Consumers' definitions of local will certainly be informed by a different perspective than those of food retailers who have developed relationships with producers across a wide range of locations.

Understanding values and motivations for carrying local food helps to clarify the participatory role of retailers in the WV local food system. Given that their primary task is profiting from food, as opposed to producing or consuming it, retailers commonly cited supporting the local economy as a reason for carrying local foods (see above: *Why are local foods carried?*). In this way, they are realizing the benefits of eating local by providing monetary support to the WV local food system. As the primary source of transactions in the local food system, retailers must price fairly in order to foster the economic health of their producers and consumers. Respondents' observations of their consumers help to elucidate their roles in local food systems. Many noted that customers understand the benefits of buying local food, an indication that their marketing efforts might have been successful. An important part of food retailer identity as participants in the local food system may be their educational role.

Control points

We have interpreted the control points[2] of a local food system to be decisions that food retailers may make to exercise control over the said system. Food retailers are well suited to influence the development of local food systems given their relationships with both producers and consumers. Key control points visible from our research include local food retailers' ability to meet demand for local food, create markets for the supply and educate consumers on local food itself.

Feenstra[52] noted that 'despite [community food system initiatives], a very small percentage of growers or consumers are interested in marketing or buying or growing local or organic produce. The sales volume at farmers' markets is a tiny fraction of food sales through huge retail

chains like Safeway, Albertson's, or Wal-Mart' (p. 14). While consumers do not generally associate the large impersonal scale of such food retailers with local food, it is clear that they are able to respond to the increasing demand for geographically proximate food. Given the variability in local food management strategies between retailers, it is unsurprising that they have decided to meet this demand in different ways. Some have significantly altered their sourcing practices to reflect an evolving set of local food values. Others have changed their marketing techniques to reflect the spatial proximity of producers they have worked with historically, rather than exercising control over their local food suppliers by reducing the total number of food miles in their inventories. Contributing to local food systems by reframing consumer education and available information rather than increasing localized economic support may be considered a less progressive strategy; however, our research plays an important role by illustrating the realities of these relationships. Without understanding the perspectives of food retailers and consciously including them, their relatively large market share may outweigh the values, goals and relationships that actors have contributed to other food system developments (e.g., the various forms of direct marketing).

It is worth noting that retailers may exercise control over the distribution of information to consumers. This enables them to control parts of the local food system in several different ways. WV retailers often actively encourage the purchase of local food in addition to simply meeting the needs of producers and consumers. They do so with materials that they and other actors in the local food system have prepared such as literature describing the benefits of sourcing locally and information about the farms they source from. One respondent described the greater transparency of direct sourcing as a form of '*social trickle-down*' in which the practices of producers within a local food system are influenced by an increasingly observant consumer base. Food retailers can also influence the way consumers view local food through marketing.

Changes

Understanding the realities, participants and control points for food retailers in the WV local food system leads to possible changes that may be made to enhance this system. In response to increasing demand for local food resources, a change that is also a significant challenge that food retailers must face is creating a working definition of local[39,53–55]. Defining local in a manner that satisfies the expectations of all participants in a local food system has been a struggle for some WV retailers. Customers that interviewees often described as '*increasingly savvy*' have been quick to notice this (for example see Portland Food and Drink[56]). Formulating a clear and widely accepted definition is important to speed up local food system development and respond efficiently to customer desires[25], and will perhaps become mandatory as government becomes increasingly involved[51,57].

In order to resolve several retailer concerns with regard to standardizing local foods (as discussed in the Results section) we propose a voluntary, transparent and scalable place-based labeling system. A possible spatial model for this could be the concept of a bioregion delineated by a naturally delimited space such as a watershed[34]. Simple spatial parameters such as driving distance or radii have the advantage of putting an individual at the center of the available food resources, but do not unify members of a community who possess their own unique sense of place in the way that bioregions can. The inclusiveness of this method would move toward meeting the recommendations of those who have worked for local food system development[52,12,58] and would also allow for scalability. The WV watershed which we presented to interviewees is composed of a dozen individual watersheds, but is also one of 22 similarly sized watersheds that constitute the greater Pacific Northwest watershed and that roughly correspond to the political borders of Washington, Oregon and Idaho[59]. In this system, individual consumers, retailers and producers have the choice to identify with a community on several different scales. This would promote identification with a naturally delineated landscape, which could help to educate consumers on the natural spatial resources required for the production of local food. Such a simple voluntary system of labeling by bioregion of origin would be appreciated by the interviewees we spoke to who expressed frustration at the amount of information they must currently maintain for each product.

Our interviews with food retailers indicated that many felt consumers do not understand the realities and challenges of sustaining vital natural resources. Connecting these consumers to the agricultural landscape through bioregional marketing may correct this, allowing participants to work more effectively to develop local food systems. The retailers we spoke to indicated that meeting the increasing demand for local foods was a primary reason for carrying them; however, they also indicated that product availability has been problematic, and that consumers would like to see more local produce. If consumers understood the capacity and land-use patterns of the WV, they might develop more realistic expectations and be able to contribute more effectively to dialogue with producers and retailers.

The inclusion of large distributors as actors may act to reconcile some weaknesses of the local food movement. The economies of scale, particularly fossil fuel use in transportation and availability of food at select times and locations, are often cited as problematic in direct agricultural marketing[3,4,13]. Retailers that remain open 7 days a week year round and receive large bulk shipments make local foods more available and efficient in terms of accessibility and energy use. Retailers in this category may be able to provide local foods at a lower price than other forms of direct marketing such as farmers' markets,

making local food available to consumers of a greater socio-economic range[21]. Food retailers' hours of operation compare favorably to other outlets of local food, which may be more limited. As noted, Norberg-Hodge[32] suggests that it is helpful to consider institutions that are able to promote local on a large scale, in this case regional and national food retailers that source foods locally with regard to marketing. Large-scale retailers have access to greater resources for materials such as signage that may engage the customers. The very act of promoting local food may spur changes and we believe that retailers, by engaging in such promotion are in a unique position to move the definition of local beyond simple spatial parameters. Acting as crucial intermediaries, food retailers are able to communicate demand for local food to producers, and to inform consumers that carrying local food may be considerably more complex than a short drive.

Conclusion

Our findings suggest a multiplicity of food retailer perspectives on what constitutes local food in the WV. These perceptions can be correlated with the store categories on the basis of basic operational differences. Retailer perspectives are useful tools in describing the realities of the local food system, which include improved food quality and a perceived increase in food security and safety. Our results also describe the spatial components used to define local food from a retail perspective, in this case most often state borders. Food retailers' responses to these realities contribute to their identities as participants who maintain relationships with both producers and consumers. These relationships create a set of control points for local food systems, presenting food retailers with the opportunity to implement changes in their marketing and acquisition strategies for local foods. These changes may be helpful in overcoming some challenges currently faced in local food system development.

'Local', whether in food or other commodities, is still very much an evolving concept, and many participants (including vendors, producers and consumers) are trying to define for themselves what it means. By studying the emerging patterns of local food marketing in the WV, our research may help create guidelines for the increasing number of communities that are developing their respective local food systems[44]. We believe that, although food retailers may create some tension with their entry into local food systems due to their differences with direct-market outlets, they may be a positive force overall due in part to the infrastructure they create. By placing local food retailers in the context of localized and international development programs such as the Dairy Creek Food Web[60], Beans and Grains Project[61], Oregon Tilth[62], a growing number of CSAs and farmers' markets, as well as new initiatives by the United States Department of Agriculture[63], our study may help other communities learn from the challenges and successes facing grocers in the WV as they source and market local foods.

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Socio-cultural aspects of cow–calf operation persistence in a peri-urban county in Iowa

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Abstract

Cow–calf operations in grass-based agricultural systems in Marion County, Iowa, are multifunctional in their provision of agronomic, ecological, economic and social uses. Since 1992, however, pastureland and cow–calf operations have decreased because of urban encroachment, leading to a speculative loss of some beneficial functions. The goal of this interdisciplinary project, conducted from 2003 to 2005, was to employ a farming systems research and evaluation platform to investigate grassland multifunctionality at farm, field and community levels. A socio-cultural analysis was conducted with the objective of identifying motivations of cow–calf operators to remain on the land despite increasing urban pressure. Environmental, as well as socio-economic, parameters were evaluated in understanding grassland multifunctionality in semi-structured interviews and a focus group. Typology classes derived from the study placed the majority of participants as maintaining integrated cattle and grain operations as full-time income sources. At the farm and community levels, themes from participants' responses suggested that the relevance of profit from a cow–calf operation is mediated by a wide range of livelihood and lifestyle choices, and that operators have diverse criteria regarding the suitability of land for pasture. Themes encompassing farm preservation and building intergenerational social capital were particularly evident among the full-time, integrated cattle/grain crop family farm members. At the community level, governmental policies rewarding practices that increase field and farm biodiversity, as demonstrated by a prairie pasture system implemented in a follow-up on-farm experiment, will facilitate greater support of grass-based systems from local institutions. In order to address the educational needs expressed by study participants, extension and federal environmental agencies are encouraged to provide relevant design and implementation recommendations in recognition of local knowledge related to farmland multifunctionality and sustainable land usage for integrated crop and livestock operations.

Introduction

Grassland multifunctionality

Within the Iowa landscape dominated by row-crops are scattered islands of grasslands, the intended home of ruminants, and often an unaccounted mélange of wild plants and animals. The tallgrass prairie once covered 140 million acres of North America, stretching from Indiana across Iowa to eastern Kansas, and south from Manitoba to Texas. More than 450 species of plants were supported through the cycle of climate, fire and animal grazing by buffalo and cattle[1]. Site characteristics include gentle to steep slopes on soil with limited available phosphorus and organic matter. After breaking the native tallgrass prairie sod or removing savannah vegetation, early settlers seeded many of these lands to Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundicacea* Schreb.) and, later, smooth bromegrass (*Bromus inermis* Leyss), for pasture and forage. Between 80 and 85% of Iowa was originally covered by tallgrass prairie[2], but today, less than 0.2% of the former prairie ecosystem remains in state preserves and numerous, undocumented and unprotected fragments[3].

In addition to high plant species richness, tallgrass prairies support diverse animal populations[1,4]. These grasslands are critical for bird abundance and richness[5], native species perseverance[6], and habitat for wildlife dependent on

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ungulate-grazed grass complexes[1]. They also are promoted for soil conservation, water quality and wildlife habitat enhancement[7–9]. Because of the fragmentation and rarity of tallgrass prairie systems, some advocate that every remnant habitat be recognized[10], but conservation theory predicts that species within native habitat islands will lose genetic diversity due to small population sizes and the difficulties of re-colonizing distant remnants once a species has been reduced[11]. Pasturelands, or 'prairie pastures', where native plants are incorporated in pasture systems, have been proposed to serve as corridors connecting native prairie remnants across the region.

Pasturelands occupied approximately 10% of Iowa's surface area and 14% of south central Marion County, Iowa, in 2002[12]. Similarly, during the same period, across the US Corn Belt, 14.1 million acres of grassland pasture and range occupied roughly 9% of the 98.6 million acres of cropland[13]. Frequently located on acreage not suitable for higher-value crop production, these grasslands are often used for cattle and cow–calf operations[14]. While row crop, fed cattle, poultry and swine sectors of the agricultural arena are marked by concentration, integration and industrialization[15], the cow–calf sector of the industry that is dependent on grassland forage is dominated by small farms[14] that function independently[16]. Small operations produce the majority of beef cattle in the USA, and control 74% of the land dedicated to beef cattle production, with three-quarters of the nation's beef cattle spending at least some portion of their life on a farm considered 'small' (130 to 2047 acres with 24–172 cows: USDA Small Beef Farm typology).

Researching grassland persistence and multifunctionality: project site and research questions

Few studies have examined the rationale behind continued use of grasslands in areas dominated by grain crop production and facing encroaching urbanization, as is occurring in Marion County, Iowa. A multidisciplinary project was undertaken in 2004–2005 in Marion County to (1) explore the socio-cultural aspects underpinning sustained grassland use in this increasingly urbanized county; and to (2) examine methods for maintaining multifunctionality and increasing biodiversity and sustainability in existing grasslands by incorporating native prairie grasses and forbs. Marion County was selected as the study site because it represented a county in transition, with many residents experiencing some pressure to sell their farmland for urban development due to its location within the Des Moines metropolitan area of 500,000 people. Despite this pressure, Marion County farmers had greater access to more diverse markets based on their proximity to a higher population base, compared to more rural counties in Iowa. We were particularly interested in determining how and why grass-based operations in Marion County continued despite significant structural and demographic urban pressure. In the companion project at the farm field level, we examined whether management practices mimicking native prairie systems could influence biodiversity within pastures, thereby contributing to ecosystem services[17,18] supported by current Farm Bill provisions.

Marion County, Iowa, characteristics

Marion County is located in south-central Iowa (Fig. 1) and represents a heterogeneous place with a broad array of farm types and influences on existing agricultural systems. Using the 'USDA-ERS Farm Typology for a Diverse Agricultural Sector'[19], we differentiated farm types into small family farms (sales < $250,000); limited-resource, retirement, residential/lifestyle, farming occupation/lower-sales, and farming occupation/higher sales. Factors influencing agricultural systems in Marion County include development pressure[20]; policy and market-driven pressure for expanded row crop production[21,22]; land ownership and demographic changes related to land ownership, such as 'acreages' (country homes owned by urbanites) and absentee-owned hunting preserves[23]; and the availability of off-farm income[24].

At the time of this study, approximately 60% of farm operators in Marion County claimed farming as their principal occupation[12]. Thirty-one percent of farm operators maintained cows and calving heifers[12]. Sixty-four percent of Marion County farms are less than 180 acres, following a bimodal distribution, with an increasing portion of farms between 10 and 50 acres, a decreasing portion of medium-sized farms (50 to 1000 acres), and a slight increase in larger farms (over 1000 acres) (Table 1). As part of the region's Combined Metropolitan and Micropolitan Statistical Area[25], Marion County has a high degree of social and economic integration with the surrounding counties and Des Moines, as measured through commuting ties. Most of the county population of 32,766 residents[25] is dispersed among two cities and seven smaller towns.

Marion County is part of a broad plain into which the Des Moines and Skunk Rivers and other tributaries have created fertile valleys. Bottomlands associated with the waterways make up about 8% of the county, nearly level to gently undulating lands make up about 15%, and the remainder is gently rolling to very steep soils on uplands[26]. Although only 1% of the county population is employed in farming[27], the 1051 farms account for 78% of the land surface[12]. The suitability of the land for row crops varies, with soils on upland ridges supporting intensive agricultural production, while the remainder is prone to erosion[28]. However, landowner expectations for cash flow from croplands contribute to pressure on these marginal lands. Agricultural land use also competes with investment and hunting interests.

In a survey promoting the use of grass-based practices in Marion County, 84% of producer respondents stated that they would be willing to include forages in their cropping systems because this is a 'more environmentally sound use

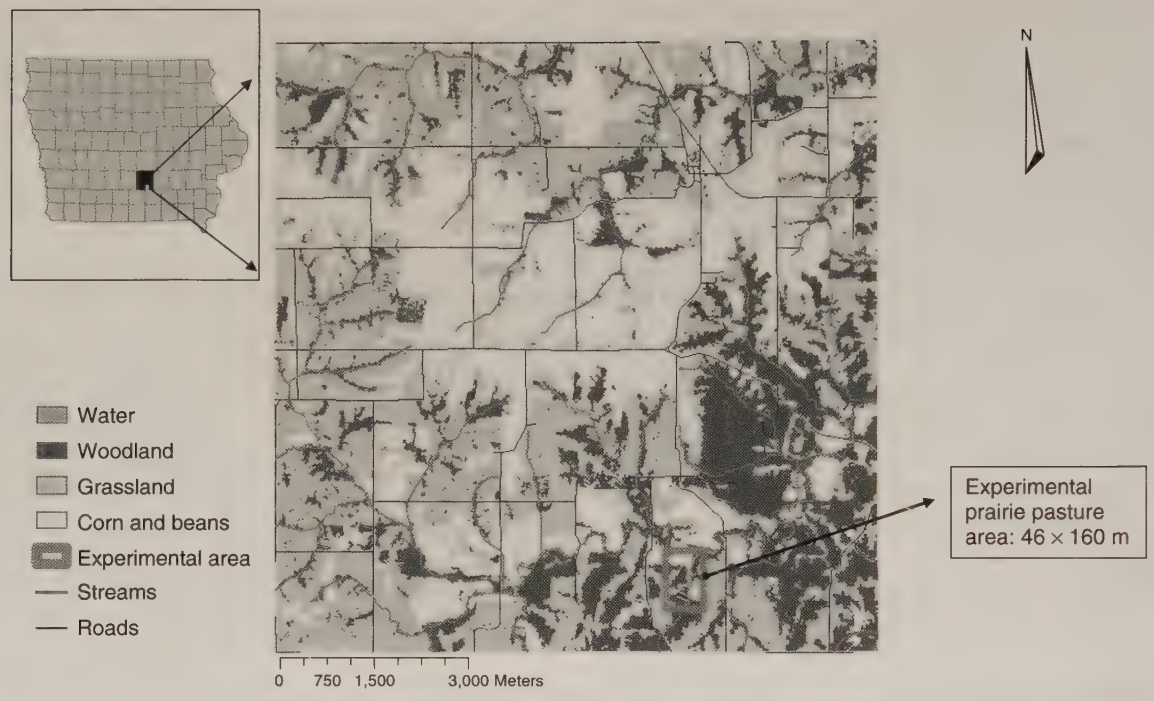

Figure 1. Study site location and landscape characteristics. The experimental area within the study site was located in Indiana township of Marion County, Iowa, at R18W-T74N at NAD 1983 UTM Zone 15N with Transverse Mercator Projection. Land-use classification is derived from satellite imagery collected in May 2002 and May 2003. Data in raster format in 15 m^2 cell size resolution. Data acquired from the Iowa DNR GIS library at http://www.igsb.uiowa.edu/./nrgislibx/. Map created by Karie Wiltshire in ArcMap 9 in October 2005.

of the land,' and 32% indicated that they would be willing to change to more grass-based systems because it would decrease risk[27]. As proposed in the socio-cultural study of this project, an understanding of the dimensions and dynamics of these decisions supporting multifunctional systems may contribute to the formulation of more effective agricultural policies that may lead to enhancing rural livelihoods and environmental protection[29].

Socio-cultural aspects of grassland farmers

In preparing for the Marion County study, we found that, for part- and full-time small beef operations in mixed row-crop and cattle enterprises, managing cows reflects pluriactivity in which the farm plays a strategic role in the household income[30], with a broad range of social, political and economic parameters mediating land-use decisions. Farming Systems Research (FSR)[31,32] began with the observation that farmers do not manage cropping systems in isolation, and led researchers to describe cropping systems of interest as but one of many subsystems on a farm. In uncovering the processes used by small farmers whose objectives may be different from mainstream farmers[33], researchers can articulate other functions of the agricultural system, such as land conservation and maintenance of landscape structure, natural resources, biodiversity, which contribute to socio-economic viability[34,35]. Complementary to FSR is the embeddedness perspective, which holds that personal behavior is strongly associated with networks of interpersonal relations, counter to atomized actor explanations of such behavior[36], and these social determinants of economic action often relate to the broader context of livelihood and lifestyle dimensions[37]. Whereas FSR emphasizes how farms and farm families are members of complex, hierarchical institutional and social structures, embeddedness explores how individual relationships to these structures influence the socio-cultural relevance of economic actions. Production practices can also contribute to cultural identities[38–40], informal exchange[41] and kinship ties[42]. Non-economic motives of economic activities were found to include the work itself, household relations, and the impact on the surrounding community in an analysis by Hinrichs[37].

Materials and Methods

Over a 14-month period in 2004–2005, farmers from predominantly grass-based systems in Marion County, Iowa, were identified and asked to describe how and why their grass-based agricultural operations were sustained. Using embeddedness and FSR perspectives as a conceptual framework, we asked the following questions: (1) what do marginal land, grass-based farmers perceive as their motivation, incentives, and limitations; (2) how do infrastructural institutions and general social relationships influence the farmers; and (3) what internal household factors, and external biological, physical, and socio-economic factors influence decisions, and how are these perceived in the light of risk? Inherent in the discussions on

Table 1. Farm size and distribution in 1997 and 2002 among Marion County, Iowa, farms[1].

	1997		2002	
Farm size	**Total farms (1059)**	**Percent of total farms**	**Total farms (1051)**	**Percent of total farms**
<10 acres	45	4.25	34	3.24
10–49 acres	187	17.66	258	24.55
50–179 acres	403	38.05	385	36.63
180–499 acres	242	22.85	212	20.17
500–999 acres	127	11.99	101	9.61
1000+ acres	55	5.19	61	5.80
Average acres	280		263	

[1] Data acquired from the National Agricultural Statistics Service, 2002.

motivations and incentives was an exploration of the multifunctionality of their farmlands and cow–calf operations.

Methods for determining typological categories included a focus group, participant observations and interviews with farmers engaged in grass-based, livestock and mixed farming operations on marginal lands, to understand the system interactions with their livelihoods and lifestyles. The intention of this research was to generate portrayals of values and opinions using accurate and effective qualitative ethnographic research procedures[43,44]. The United States Department of Agriculture-Natural Resources Conservation Services (USDA-NRCS) Knoxville (Marion County) office was an additional observation point. Serving as a participant–observer[45], one member of the research team (K. Wiltshire) volunteered her services during the summers of 2004 and 2005 at the USDA-NRCS office and developed relationships of exchange and understanding with community members. Participation in agricultural events focusing on cow–calf management also served as bases of observation.

Observation sites and identification of participants

In developing the initial typology, Marion County agriculture professionals from Iowa State University Extension and the USDA-NRCS identified five individuals with cow–calf operation experience to assist in this effort. These individuals constituted the focus group, which was organized by the graduate student (K. Wiltshire), with assistance provided by Extension and NRCS, to help develop an initial typology of cow–calf operators in Marion County. Using participatory group facilitation methods[46], the typology was developed with the goal of grouping individuals on the basis of similarities for determining their respective group opportunities and constraints[47,48]. An outcome of the typology development was an increase in governmental agency understanding of the main types of cow–calf operators in Marion County: key elements of their production systems; the amount of time available to commit to this type of operation; their motivations for continuing a cow–calf operation; and the levels of success they are experiencing in maintaining this type of livelihood in the face of urban pressure. Typologies can also be used to establish a framework for identifying potential areas of cooperation among group members, such as coordinating aggregation of cattle, transportation and marketing among cow–calf operators to cut transaction costs and increase sales. By representing a group, these cow–calf operators could foster greater equality with governmental and financial organizations, which could lead to income/livelihood enhancement[49].

After initial typology development and operationalization, the FSR procedure of 'diagnosis' described by Sutherland[32] was used to identify other farmer participants for the study to maximize differences between typology classes and to minimize sources of variation within them[33]. The goal of the typology, however, was not to isolate participants into a permanent group, since typologies seek to only approximate groups or clusters[47], and, ideally, increase the probability that the specific group will react in a certain manner. Snowball and purposive sampling[45], based on focus-group members' suggestions, was employed to obtain in-depth interviews with a total of 21 farmers and nine agricultural industry employees from June 2004 to June 2005. Agricultural industry employees were interviewed strictly to facilitate further understanding of cow–calf operations in Marion County; the typology reflects only the categories developed with farmer participants. For initiating snowball sampling, each participant was asked for a referral to someone they felt would be willing to be interviewed. Two other farmers were identified at agricultural events and interviewed.

Qualitative data collection and analysis: data recording, organization and analysis

During the focus group and interviews, the interviewer identified herself as a graduate student conducting the analysis solely for educational purposes. To protect confidentiality, the identity of participants was not recorded. Each interview began by acquiring informed consent and explaining standard interviewing procedures, including

permission to use an audio recording device. An Olympus® Digital Voice was used for all but two of the interviews. All records associating the particular discussion or interview with the participant's identity were destroyed after data entry. Audio-recorded interviews were transcribed with the assistance of an Olympus® Digital Wave Player (Olympus®, Center Valley, PA, USA) and Dragon Naturally Speaking 8.0 software (ScanSoft® Inc., Burlington, MA, USA). The transcription of the interviews was analyzed with grounded theory open coding and focused coding for themes[50] using the Qualrus® Intelligent Qualitative Analysis Program (Idea Works Inc., Columbia, MO, USA). In the transcription, 'farmer' referred to the primary decision-maker on the farm, although, as noted by Hinrichs[37], the 'primary decision-maker' is often a role allocated to an individual based on what type of decision is being made. While several household members often participated in an interview, each participant household is referred to as the 'farmer' for ease of analysis. The typology categories developed from the focus group were then further refined to reflect differences from interviews with the full group of participants.

Vignette case-study research

Sets of themes or concepts were identified throughout the analysis of focus group and interview content to determine linkages and relationships, following methods described by Miles and Huberman[51]. Correlations were qualitatively identified between themes and assigned typology. The themes were then incorporated into the summarizing typology classes to present results in a form of models of ethnographic collective case studies[43,52,53]. Homogeneous and contrasting codes within themes among case members were compiled as generic 'vignettes' about the typology case[54], including quotes from participants as exemplars of concepts, theories and negative cases[50] in a narrative approach[55]. Triangulation, or the use of diverse methods for the acquisition of information about the people and scenario, such as the interviews, focus group and participant observation among several different social groups, aided external validity[45].

Results and Discussion

Typology development: income relevance, livelihood system and values

In determining the answer to the principal question: 'What do marginal-land, grass-based farmers perceive as their motivation, encouragement, and limitations within their farming systems?', several general tendencies emerged. Through the focus group and interview analysis, 36 codes were identified under 13 themes. Particular typology showed strong salience with the associated themes, demonstrating that typology class was an effective method for summarizing the data. Although heterogeneity among study participants' responses was observed, the typology category, 'income relevance', had classes that cohesively grouped the most members. Following this segregation, each typology class was analyzed under the parameters of 'livelihood system', 'values and desired futures' and 'integrating livelihood and values' (Table 2). Analyzing cow–calf operations through the lens of income-relevance typology classes shed light on differences among operations, which resonates with recent farming systems research studies advocating the recognition of diverse socio-economic and biophysical influences on farming systems[56,57]. All 21 farmer participants whose focus group and interview responses were utilized in the final typology development were placed in a specific typology class, based on similarities in income relevance, livelihood system and values. Participants verified their typology class after researchers completed the typology exercise.

Integrated livestock/crop operation: full-time income source. The majority of participants in this study maintained integrated cattle (cow–calf, calf-to-finish, stockers or feeders) and grain operations as full-time income sources. Thirty percent of the participants in this typology class had spouses with off-farm jobs. Each of the farms depended on family members for labor and management, although several employed assistance and custom work. Most of the participants matched their cattle herd numbers to what they considered their land and labor base. None felt constrained by land limitations nor pursued land acquisitions to increase their herd sizes. Rather, they hoped to gain additional lands to avoid the negative perceptions of farming by recent ex-urban neighbors.

The full-time integrated operation participants were continuing a family farm, with most farming the original family homestead. Most identified themselves as full-time commodity farmers, and described membership in 'conventional' groups such as Farm Bureau, grain interest groups, the Iowa Cattlemen's Association, and local co-op boards, although one family engaged in full-time operations identified themselves with 'alternative' agriculture. Participants considered raising cattle, grains and hay in a complementary fashion utilizing crop rotations and manure distribution. The size of the operations managed by the integrated full-time class was highly variable, suggesting management of a mixture of rented and owned land, although most owned the majority of their pastureland. The range of herd sizes was 38–120 cows or 300 feeders, with an average of 96 head. The managed farmland size ranged from 200 to 4500 acres with an average of 1444 acres, and managed pastures ranged from 140 to 500 acres with an average of 288 acres. Forty percent of participants operated rotational grazing systems under a USDA Environmental Quality Incentive Program (EQIP) contract, although most others managed their pastures under a rotational grazing system not subject to third-party oversight.

Sixty percent of these participants primarily sold their grains and the remainder used some portion as feedstuffs while selling the balance. The majority of full-time farmer

Table 2. Typology class characteristics of cow–calf operators developed from focus group, interviews and field observations in Marion County, Iowa, 2004–2005.

		Typology class (income relevance)		
	Characteristics	**Integrated crop-livestock: full-time farmer ($n = 10$)**	**Exclusive livestock: part-time farmer ($n = 9$)**	**Integrated crop-livestock: part-time farmer ($n = 2$)**
Livelihood system	Farm description	Majority fields owned; pasture integrated with row crop fields; average herd size: 96	Majority fields owned; exclusively intended as pasture; average herd size: 59	Fields rented and owned; mixture of exclusive pasture and integrated with row crop fields; average herd size: 80
	Cultural membership/ heritage	Dominantly continuing farming, with identification as commodity farmers	Mixture of new, returning and continuing operators with heterogeneous identification	Returning to farming, with heterogeneous identification
	Marketing strategy	Dominantly cow–calves using sale barn and contracts with relatives; some stocker/feeder operations	Some cow–calf at sale barn, mostly direct sales of beef or breeds and contracts	Mixture of strategies with cow–calves and stockers
Values and desired futures	Values	Soil conservation, land stewardship	Participation in enjoyable/wholesome activity; benefits children; opportunity for entrepreneurship and challenge	Participation in enjoyable/wholesome activity; benefits children
	Future	Half have family that will continue operation; half unknown or definitely unlikely	Few with definite plans	Some with definite plans

participants considered convenience, proximity and trust when choosing marketing strategies for their livestock, using the regional sale barn as their preferred marketing site. The remaining group used more complex marketing strategies, including the regional sale barn to sell 'bottom-line' cattle, access new buyers or sellers, or sell in different seasons. Despite the mixed attitudes, the sale barn was considered a dependable, competitive income source for the participants, with several returning to the sale barn after trying other venues. Several spoke about loyalty to the local sale barn:

> I purposely try to patronize it to help keep them in business. All of our cattle go through there, and most of the cattle I buy come from there. It works well for my operation.

The need for convenience and trust also influenced a significant reliance on familial relationships to sell or contract calves and stockers to relatives for feeding.

Multifunctionality of pasture systems. While convenience influenced livestock marketing, pastureland use was mediated by its contribution to a sustained livelihood. Pastures were justified with a cost–benefit comparison to that of row-crops. Limiting factors included accessibility, incompatibility to machinery size, and need for terraces and drainage. As described by one member of the group:

> I believe in full utilization of the land relative to soil constraints. If it's not suitable for farming, let's pasture it; if it's suitable for both, we still have some waterways and headlands that we're going to harvest for the livestock.

Some argue the land-use criterion employed by participants is what Glenna[58] considers an 'instrumental rationality' in which farmers alter their land and techniques to improve productivity and efficiency while employing soil-saving techniques. Land-use perspectives, both on- and off-farm, were strongly associated with livelihood strategies for full-time integrated operations.

Perceived threats to livelihoods included residential zoning of surrounding land and complaints about odor, tractors and chemicals. Participants indicated plans to purchase surrounding farmland, or rent land from new residents. As one participant observed:

> Many people who work with farmers just want their ground in row crop, so I was surprised when I learned that many I've worked with are quick to say they want it in hay. They are really concerned about the way the farm looks when people drive by.

These farmers often provide services such as snow plowing to new owners in the interest of maintaining amicable relations and preventing farming interruptions. Other farm operators explored new markets, including hay sales for new residents with horses, and beef sales.

Values and desired future. Assertiveness, in the form of opportunism within a changing social landscape and demand for farmland, was a strategy of several participants, but 40% of full-time farmers adhered to values and

family contexts that prevented selling land. A family farm with a long agricultural heritage guarded their farm:

> Everyone wants our land, but our family will sell nothing. It's so hard to get land, and we are really married to it. We're not the kind to sit and enjoy money from a land sale. This is everything, it is our life. It's so heartbreaking to watch farms get sold to investors around here.

Despite the uncertainty about farming, participants with children emphasized passing on values they associate with agriculture. Seventy percent of participants with children encouraged them to participate in government-sponsored agricultural youth groups, such as 4-H and FFA. Comments about farm-related skills, work ethic and independence were abundant among the full-time integrated typology participants, as were commitments to land conservation.

A strict economic motive was diluted by indicators of embeddedness as participants discussed their rationale for managing pasture and cattle. The social capital and inherited linkages that several experienced through family were pivotal to their current cattle operation. Other participants used their social capital for entrepreneurship, and partially justified their operation with that capital. Regarding their decision to sell beef to friends and neighbors, one couple explained, 'We don't make much of a return on it; we just figure they deserve to eat good beef.' Other participants associated cattle production with lifestyle dimensions they considered important:

> I look at it as a way of life. It's a good place to raise children, you're constantly involved with nature, and you're outside everyday. These are things that city people pay to see.

Cultural and ethnic studies of full-time agricultural operations have observed similar decisions mediated by socio-cultural attributes rather than strict profit maximization[59,60]. Other studies have found that the path and success of entrepreneurs is derived from socio-cultural relationships, and that this social capital is critical to decision-making and persistence[61,62].

Integrating livelihood and values. The livelihood of the full-time integrated operators is dependent on their crops and land-use strategies and reflected by their approach of matching soil and topographic characteristics to pasture-land. Although a common response to a question defining characteristics of cattlemen was 'independence,' all of the full-time integrated operators in the study participated in government crop programs. They expressed frustration with government programs that lacked recommendations for their topography or climate, reinforcing a desire for institutional recognition of local knowledge[63–65]. Participants also voiced frustration about this void in extension programs and criticized government programs that encouraged plowing of erodible lands.

Exclusive cow–calf operation: part-time income source. Those participants who solely maintained cattle did so as part-time operators, with either full-time off-farm employment or as retirees. Approximately 25% of the participants in this group stated that labor availability constrained their operations and 25% stated land size restricted expansion. The heterogeneity of constraints affecting the participants is consistent with work by Lawrence and Schuknecht[66] who found labor availability a variable constraint to farm management, and land as an occasional obstacle to profitable, optimum size operations. Although several of the operations were not located on family homesteads, the decision to maintain operations was closely associated with heritage or identity. Some participants were continuing their family traditions:

> With the cows, you're taking care of the soil. My dad's mother grew up here, so it's been in the family forever. We're going to keep that ground, so we might as well take care of it.

Very few of the part-time cow–calf operations generated substantial income on which the operator or the family depended, although it was a valued supplement to several who identified themselves as 'cattlemen' or 'graziers'. For these producers, managing a cow–calf operation provides a claim to the rural or country identity[38,37]. All participants in this group owned the majority of the land used for their cow–calf or grass operations. Farms ranged from 20 to 3200 acres with an average of 499 acres, managed pastures ranged from 20 to 1200 acres, with an average of 219 acres, and herd size ranged from 8 to 200 head, with an average of 59 cows.

Multifunctionality of pasture systems. Acreage owned by the exclusive livestock operators ranged from 'high crop suitability' to 'highly erodible' land. A livelihood strategy not dependent on cattle-related income influenced the capacity of this typology group to be flexible in land-use options. Some participants pasture the erodible ground and rent the remaining land, while others manage all land as pasture. Although the pasture and cattle management tactics were highly varied among this group, all but one managed their pastures as 'whole fields' in which the entire field is exclusively pasture (rather than being associated with nearby row-crops). This trend may be related to lack of other uses or labor limitations. Similar to integrated crop-livestock operators, most exclusive livestock operators manage their pastures under a rotational system, with 40% of this group participating in rotational grazing systems supported by USDA-EQIP programs.

The marketing strategies among exclusive part-time operators varied, often guided by experimentation. Sixty-six percent of the part-time operators engaged in some form of direct marketing, through sales of beef to neighbors, friends or clients, or through the sale of breeds and club calves. These participants associated their operations with challenges rewarded monetarily, or with the satisfaction of providing good products. The thrill of marketing innovative ideas and breeds motivated some:

> The biggest reason we're in this business is because we enjoy the people and the satisfaction of raising cattle that other people want to buy for a premium.

The part-time exclusive participants managed their farms with intention. Living in, or protecting, the countryside while engaging in a particular lifestyle was their goal, and expressed concern about changes to the countryside. Depopulation associated with row-crop expansion and animal confinement operations concerned another. Others expressed concern about the future:

> The demand from people who have money on the outside, like hunting or investment circles is stronger than from ag circles. That's a real challenge for us. Young people can't enter the cattle domain because land costs too much to rent.

Values and desired futures. Part-time exclusive cow–calf operations were motivated by the values embedded in the process of caring for cattle, as explained by one participant:

> It just gets in your blood. It's the satisfaction you get looking at those calves and knowing that the management decisions were good, and when a sale comes up in the fall, getting the satisfaction of a good sale.

Such comments suggest that cow-calving is embedded in a rural culture, and it serves needs that are separate from, although not at odds with, livelihood[37]. This embeddedness of cow-calving among part-time exclusive participants was a pervasive theme within this typology. The role of the cow–calf operation was as an 'end use' for the majority of participants who specifically value cattle as both a process and a product for the farming operation. Half the participants who associated the process of caring for and marketing cattle expressed a desire to benefit their children or society at large in non-economic ways, while the same percentage saw their livestock enterprise as fulfilling their personal desire for challenge, invention and entrepreneurship. 'Stewardship' of land, wildlife and natural resources, and 'learning ethical issues and life lessons' from cattle raising were also mentioned by several members of this group. Only one of the participants confirmed the continuity of their farm. Despite the uncertainty about farming, four participants with children emphasized passing on the values associated with agriculture and encouraged their children to participate in 4-H and FFA groups.

Integrating livelihood and values. Livelihood and lifestyle dimensions motivated exclusive cow–calf, part-time income participants to maintain their operations. They were able to manage cattle, allocate pastureland and market their products with flexibility and innovation, attributes made possible by additional means of income and because of values encouraging animal husbandry and land stewardship. Most distinguished themselves from row-crop farmers, and made decisions for land-use that were sometimes in reaction to previous row-crop use. Some expressed concern that current trends in row-crop or animal-confinement agriculture were degrading their quality of life in the countryside.

Integrated livestock/crop operation: part-time income source. The smallest group identified through the purposive sampling process maintained integrated cattle and grain operations as part-time income sources with spouses having off-farm jobs. Because of the small number of participants in this sample, only prominent trends derived from this group are described. This group managed a mixture of rented and owned farmland, averaging 633 acres, and an average of 395 acres of pastureland, with a mean herd size of 80 cows. Family members provided labor and management support. Pastures were managed in rotational systems, but they did not utilize USDA-EQIP contracts.

As suggested by the class title, many characteristics of this group were a blend of the exclusive part-time and the integrated full-time operator types. Each participant grew up on a farm, although each left and then returned to farming after becoming established in a professional field. One returned to the family farm homestead motivated to continue the family farm operation. Although they marketed their grains, they emphasized the cow–calf component on their farm, allocating more time and interest to it compared to the smaller corn and soybean component. They explain the cow–calf operation as such: 'For us, it's a family thing. We like to do it, and it fits our schedules well.' The cattle operation fits their livelihood because of compatible labor needs and an existing land base. Identity and preference for the countryside and the values associated with raising cattle reinforced their desire to return to the farm. The decision to maintain cropland for this operation was influenced by the existing allocation of land to row-crops as well as the skills and machinery available. The part-time integrated cow–calf and row-crop operators also stated that their operations serve purposes related to family, identity and enjoyment, similar to the embeddedness observed among the part-time exclusive cow–calf operators, but built on the integrated operation model that is attentive to efficiencies as observed in the full-time integrated operators.

Typology class comparison

Income relevance. While there was some heterogeneity within each typology class, the integrated full-time operation participants were overwhelmingly guided by livelihood strategies, which was consistent with work by Cashman[14], who found that income reliance sculpted feasible management strategies among the small-farm cattlemen group. This class also identified themselves uniformly as commodity farmers. Within the other typology classes, the decision to maintain cattle was the most unifying characteristic among members of the part-time farmer groups, not income reliance. This heterogeneity could bear consequences when a single label, such as 'commercial cow–calf operation', is used to develop programs, which is salient with perspectives articulated by Bourdieu and Wacquant[67] and Glenna[58] in which the logic of accumulation of capital and commodification of land is the dominant agricultural label. These distinct

identities among the exclusive part-time class could also affect political empowerment, as suggested by FSR[68].

Governmental support and marketing. All the full-time and part-time integrated operators used were aware of infrastructure, institutions and policies to facilitate their work, although several expressed concern about relevant design and implementation. The part-time exclusive cow–calf operators were less engaged in, and less aware of, government programs, although several were grateful for opportunities to participate in programs such as USDA-EQIP. Regarding marketing, the availability of a reliable, equitable marketing venue such as the sale barn appeared to be sustaining cow–calf operations in the region. Similarly, Cruise and Lyson[69] and Schwarzweller and Davidson[70] noted that diverse structural components, such as educational systems, market competition and access to reliable sources of information, significantly contribute to community productivity of animal operations.

Multifunctionality of pasture systems. Pasture systems among full-time integrated cattle and grain crop operators were generally 'integrated fields' used for both row crop and cattle, and were dependent on the season and the crop rotation. The part-time operators tended to use fields exclusively for cattle. This difference suggests that part-time operators may be more willing candidates for long-term perennial vegetation projects and habitat development, such as the multifunctional prairie pasture system developed with a member of this group in a follow-up agroecological on-farm experiment[71]. Integrated operators may benefit from policies and practices rewarding the incorporation of soil quality-enhancing pastures and longer crop rotations through carbon sequestration credits proposed in federal regulations.

Rural viability. The future of the family farm was uncertain in all typology classes. Among all the participants, 33% were confident that their operation would not continue as such when they retired, which is consistent with findings by Lawrence and Schuknecht[66], who determined that 42% of operations with more than 100 heads of cattle would not be passed down to family members. Only one of nine participants in the exclusive part-time class was confident of the continuation of the farm in the future, suggesting that those in this typology had a tendency to consider the operation as a lifestyle choice and as an identification of residence in the rural countryside[37].

Conclusions from the Socio-cultural Study

From this socio-cultural study of cow–calf operators in Marion County, Iowa, an agricultural area facing increasing pressure from urban development, it could be argued that many part-time exclusive cow–calf operator families are strongly motivated by a desire to maintain an agricultural heritage and image[37], while integrated crop-livestock operators are more influenced by economically driven instrumental rationale[58]. The motivation to participate in, and otherwise maintain, labor- and knowledge-intense practices is embedded in complex socio-economic and socio-cultural systems[37] and supported by both household and structural support mechanisms[69]. The integrated full-time operation was strongly influenced by livelihood-oriented parameters and matched livelihood needs with their land use and cattle operations, although participants were influenced by social relationships and values as they planned and executed their operations.

The importance of maintaining multifunctional farmlands and protecting biodiversity also was inherent in focus group and interview discussions. Multifunctionality recognizes that, while the primary role of agriculture is producing food and fiber, other functions, such as land conservation, maintenance of landscape structure, sustainable management of natural resources, biodiversity preservation, and contributions to the socio-economic viability of rural areas[34,35], are also valuable—a sentiment expressed by many members of the cow–calf operator typology classes. The overall multifunctional profile of grass-based lands in Marion County, as described by study participants, included environmental attributes, such as preventing erosion by maintaining lands in pasture; economic benefits resulting from cow–calf sales; and social connections contributing to the stability of the rural community. Vignettes developed from this typology and interview process can be used to understand the human dimension underpinning the persistence of grass-based farms in this county, in order to create effective policies for farmland conservation and rural preservation. Policies in Japan, South Korea, Norway and Switzerland have supported the concept that small- to moderate-sized independent farms can help enhance the economic, environmental and social health of rural areas and preserve cultural heritage[72]. As European Union polices have placed monetary value on the non-market benefits of agriculture, such as biodiversity preservation, current commodity-production policies in USA could be shifted for providing more environmental, social and economic benefits[73,74], as Americans are increasingly recognizing the public benefits embedded in private agricultural systems[75].

Biodiversity enhancement in agricultural systems can be achieved by incorporating native grasses and forbs into otherwise marginal rangeland or pasture, which falls within the mandate of the Conservation Stewardship Program (formerly the Conservation Security Program) ('CSP') as authorized in the latest US Farm Bill (Food, Conservation, and Energy Act of 2008). Government programs, such as the CSP and EQIP, can provide incentives for sustaining a farm landscape consisting of diverse, grass-based agricultural systems that support rural livelihoods and environmental quality. In the second phase of this project, a full-time cow–calf operator from the study group, operating in a direct-market scheme, demonstrated the potential for prairie pastures to enhance the biodiversity and sustainability of his grassland system[71]. Additional research is

required to determine the transferability of these results to other regions. In more rural counties, with less urban development pressure, land values would be lower, and off-farm employment opportunities would be more limited. Marketing opportunities would be greater in a peri-urban county, such as Marion County, Iowa, where higher rates of disposable income are available to support farmers marketing products with perceived environmental benefits.

Governmental support for the implementation of conservation-focused agricultural systems, such as prairie pastures, will lead to an increase in ecosystem services on working lands[76], while reducing inputs based on limited fossil-fuel resources. In order to address the educational needs expressed by study participants, Extension and federal environmental agencies are encouraged to provide relevant design and implementation recommendations in recognition of local knowledge related to farmland multi-functionality and sustainable land usage for integrated crop and livestock operations.

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The potential of herbaceous native Australian legumes as grain crops: a review

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Abstract

Many agricultural systems around the world are challenged by declining soil resources, a dry climate and increases in input costs. The cultivation of plants that are better adapted than current crop species to nutrient poor soils, a dry climate and low-input agricultural systems would aid the continued profitability and environmental sustainability of agricultural systems. This paper examines herbaceous native Australian legumes for their capacity to be developed as grain crops adapted to dry environments. The 14 genera that contain herbaceous species are *Canavalia, Crotalaria, Cullen, Desmodium, Glycine, Glycyrrhiza, Hardenbergia, Indigofera, Kennedia, Lotus, Rhynchosia, Swainsona, Trigonella* and *Vigna*. A number of these genera (e.g., *Glycine, Crotalaria, Trigonella* and *Vigna*) include already cultivated exotic grain legumes. Species were evaluated based on the extent to which their natural distribution corresponded to arid and semi-arid climatic regions, as well as the existing information on traits related to harvestability (uniformity of ripening, propensity to retain pod, pod shattering and growth habit), grain qualities (seed size, chemistry, color and the absence of toxins) and fecundity. Published data on seed yield were rare, and for many other traits information was limited. The Australian species of *Vigna*, *Canavalia* and *Desmodium* mainly have tropical distributions and were considered poorly suited for semi-arid temperate cropping systems. Of the remaining genera *Glycyrrhiza* and *Crotalaria* species showed many suitable traits, including an erect growth habit, a low propensity to shatter, flowers and fruits borne at the end of branches and moderate to large seeds (5 and 38 mg, respectively). The species for which sufficient information was available that were considered highest priority for further investigation were *Glycine canescens, Cullen tenax, Swainsona canescens, Swainsona colutoides, Trigonella suavissima. Kennedia prorepens, Glycyrrhiza acanthocarpa, Crotalaria cunninghamii* and *Rhynchosia minima.*

Key words: domestication, novel crops, perennial, adaptation, arid, climate change

Introduction

Increasing crop diversity can reduce our reliance on just a few major food crops and improve the sustainability and resilience of agriculture in the future[1,2]. With dry climatic conditions, reduced allocations of water for agriculture and increasing demands for food production from currently marginal areas, species adapted to more stressful environments are needed. In addition, alternative crops with improved efficiency of fertilizer use and reduced reliance on pesticides would improve the sustainability of our agricultural systems[3]. Benefits of protection of soil from erosion, reduced leaching of water and nutrients, and additional forage for livestock could also be provided by perennial grain crops[2,4,5]. Exploring the wild native flora provides an exciting and substantial opportunity to identify species with potential as alternative grain crops for the future[6].

Australia, because of its arid climate and infertile and poor soils, is a good place to look for potential new grain crops adapted to harsh growing environments. Yet, the potential of Australia's native flora for use in agriculture has been relatively underexplored. Some Australian grasses and legumes have been investigated as potential pastures or forage species[7–13], but little work has been conducted on their suitability as grain crops. Woody legumes such as *Acacia* spp. could have some use as alternative sources of

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grain[14], but herbaceous species are more suited to modern broad-acre farming systems because they can be mechanically harvested and are more easily removed and rotated with other crops. One Australian grass, *Microlaena stipoides*, has been investigated to a limited extent for grain production[15], yet herbaceous legumes have received little attention. Rivett et al.[16] examined a number of native Australian plants for their potential as grain crops and found that the legumes *Hardenbergia violacea*, *Crotalaria cunninghamii* and *Kennedia nigricans* warranted further examination as they possessed relatively large seeds with substantial amounts of crude protein and oil.

There are a few modern examples where efforts have been made to domesticate legumes for grain production in agricultural systems where grain legumes are/were lacking; *Lupinus angustifolius* (narrow-leafed lupin)[17], *Lupinus luteus* (yellow lupin)[18] and *Desmanthus illinoensis* (Illinois bundleflower)[19]. Evidence with these species and advances in our understanding of crop domestication and in the technologies associated with crop breeding should allow rapid advances in the future[20]. However, the domestication of Australian legumes may be more difficult, as there is little or no history of predomestication. This means that the net may need to be cast wide, as many species are unlikely to possess traits common to domesticated plants[21]. While Australian aboriginals manipulated their environment to ensure food supply, notably through the use of fire, they did not generally practice agriculture in a way close to modern cultivated cropping systems. In addition, while seed grindstones have been found in many areas and there are reports of aboriginal seed collecting from grasses and of the use of seed from ~50 species of *Acacia*, there is no indication that the seeds of native herbaceous legumes were other than a very occasional source of food[22]. Hence, Australian native herbaceous legumes have not been subjected to the same predomestication pressures that have acted upon other species that have been cultivated by ancient peoples or were simply present (as weeds) in early agricultural systems[23,24].

We examined the 14 genera of Australia's native legumes that contain herbaceous species for their suitability as grain crops. While little useful information was available for many species, we found that at least nine species merit further investigation. Species identified were most likely to be adapted to the climate of Australia's semi-arid cropping regions, but they may have applications in other semi-arid environments throughout the world or in areas predicted to experience a dry climate in the future.

Approach and Desirable Plant Attributes

Among Australia's legumes, there are 14 genera that contain herbaceous species. Information was gathered on three main aspects: species distribution in arid or semi-arid climatic range; traits related to harvestability, grain size and yield potential; and grain chemistry and nutritional qualities (discussed below). Some genera also include currently cultivated grain legume crops exotic to Australia (e.g., *Glycine*, *Vigna*, *Trigonella* and *Canavalia*). This close relationship could indicate genera that possess suitable agronomic characteristics, or closely related species that may be suitable for hybridization with the cultivated crop, to either improve the agronomic traits of a wild species or transfer desirable characteristics into the cultivated species (e.g., abiotic or biotic stress tolerance)[5]. The hybridization of Australian perennial *Glycine* species with soybean is one such example[25,26]. Together, this information is used to identify genera and species with the most desirable attributes and the greatest immediate potential as grain crops. Information was not available for some aspects of some species, particularly in rarer or less studied species. Hence, suppositions were drawn only where sufficient information was available. Other species may also have desirable characteristics or potential in different agro-climatic conditions. Beyond the scope of this review was an assessment of the weed risk of these species. Indigenous species can be regarded as weeds when growing outside their natural range, and some species of Fabaceae are commonly mentioned in this context in Australia including some of the genera assessed in this paper[27].

Potential adaptation to arid and semi-arid environments

Information on the distribution of Australian native herbaceous legumes was obtained from collection locations available from the Australian Virtual Herbarium[28] and matched against Australia's agro-climatic regions[29]. Species were prioritized if their distribution corresponded to the arid interior (G and E6) or semi-arid environments with sufficient capacity for plant growth in winter–spring (E2, E3 and E4) (Fig. 1). Species that occur in these agro-climatic regions likely possess adaptations to short or erratic growing seasons, and hot and dry climatic conditions, such as physiological drought tolerance mechanisms or reproductive strategies which enable them to avoid these stresses (e.g., rapid flowering and deep roots). Excluded from the target region were tropical (i.e., H, I1, I2, I3, J1, J2 and E7) and cold climatic (i.e. B1 and B2) regions, because plant growth is limited during winter–spring due to lack of moisture and cold, respectively. Also, Australian species from northern origins are more likely to have flowering promoted by short days (short-day plants), while long-day plants grow at higher latitudes, including the Australian agricultural zone. Short-day plants have limited potential in these southern temperate areas. Although cool-season grain crop production is common in agro-climatic regions E1 (wet 'Mediterranean') and D5 (cool-season and wet), the target region was restricted to the less favorable climatic regions with a shorter winter–spring growing season (i.e., E2—dry 'Mediterranean', E3—temperate, subhumid and E4—subtropical, subhumid). Agro-climates F3 and F4 are warm and wet environments and were also excluded as they have a few climatic stresses

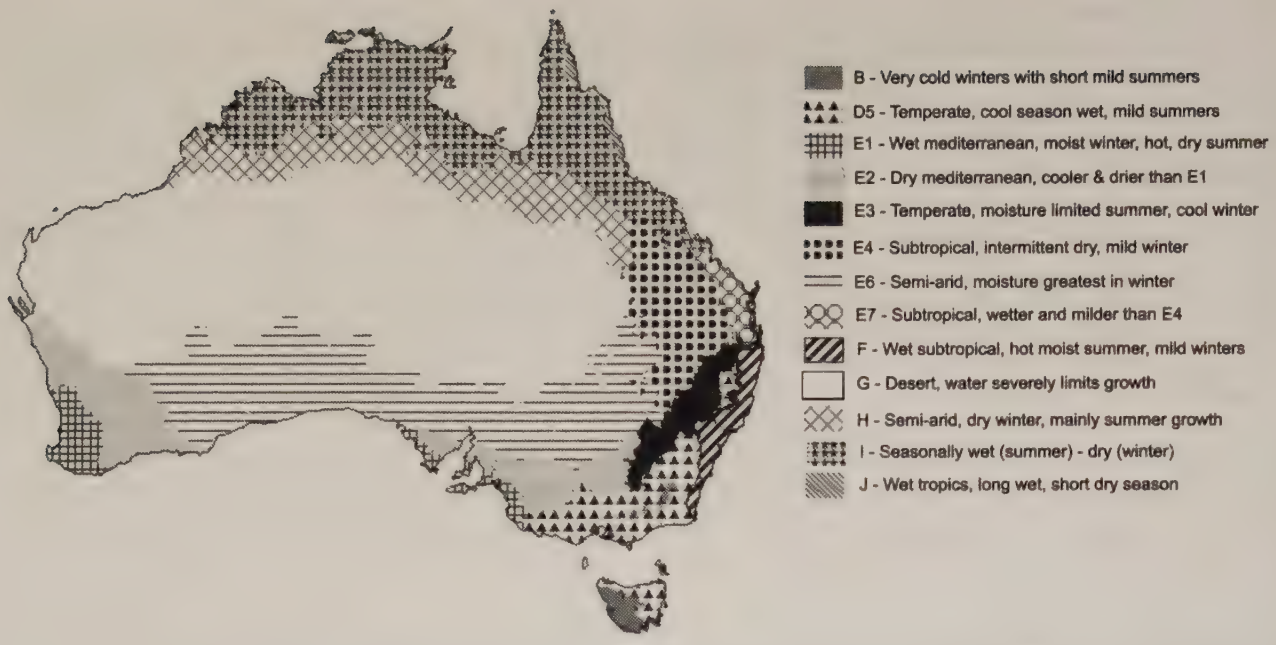
B - Very cold winters with short mild summers
D5 - Temperate, cool season wet, mild summers
E1 - Wet mediterranean, moist winter, hot, dry summer
E2 - Dry mediterranean, cooler & drier than E1
E3 - Temperate, moisture limited summer, cool winter
E4 - Subtropical, intermittent dry, mild winter
E6 - Semi-arid, moisture greatest in winter
E7 - Subtropical, wetter and milder than E4
F - Wet subtropical, hot moist summer, mild winters
G - Desert, water severely limits growth
H - Semi-arid, dry winter, mainly summer growth
I - Seasonally wet (summer) - dry (winter)
J - Wet tropics, long wet, short dry season

Figure 1. Agro-climatic regions of Australia (adapted from[29]). The target climatic regions include the arid and semi-arid regions too dry for field crops (i.e., G and E6) and the semi-arid cropping zone where moisture is a major growth limitation and with sufficient capacity for growth in winter–spring (i.e., E4, E3 and E2).

that reduce plant growth throughout the year. A wider species distribution was also regarded as favorable as it suggests greater adaptability and a greater capacity to exploit within species variability.

Harvestability

Plant traits that influence grain harvestability are critical in the domestication process[30] and hence were considered important aspects for evaluating the agronomic potential of wild legume species. Plants with a self-supporting, erect or semi-erect growth habit and those that set pods close to the top of the plant would be most favorable for mechanical harvesting, while highly prostrate species may be difficult to harvest. Species with a twining or rambling habit were not regarded as ideal, but were not removed from consideration. Many current grain legume crops originated from ancestors with a climbing, creeping or straggling growth habit and their domestication has shortened internode length and reduced indeterminate branching (e.g., *Phaseolus, Vigna, Glycine, Pisum* and *Arachis*)[31]. Pod dehiscence and indeterminate growth habit is ubiquitous among undomesticated legumes and domesticated grain and forage legumes alike (e.g., soybean[32] and birdsfoot trefoil[33]). While pod indehiscence (non-shattering) overcomes some agronomic challenges, it is clear that this is not a disqualifying trait, as selection for indehiscence during domestication has occurred for most modern crops and would also occur in native Australian legumes.

Grain size and yield potential

Legume grain or seed size is obviously an important aspect as it influences the potential market uses and agronomic performance. Large seeds also offer advantages for crop establishment especially from greater depth, under greater competition (e.g., weed burden) and in low-nutrient or moisture conditions[34]. Cultivated grain legumes have large seeds compared to their wild relatives and seed size has been increased substantially through active selection, and hence it is likely that the seed size of wild legumes would be smaller than that of cultivated grain legumes. For example, the seed size has increased at least tenfold in *Phaseolus coccineus* (French bean) and by at least fivefold in other legume species[31]. This is also demonstrated in the germplasm of *L. angustifolius* (narrow-leaf lupin), where seed size may vary substantially from 29 to 244 mg, with the 'wild' types generally smaller seeded[35]. Despite the appeal of species with larger seeds, small seeds may actually be equally appealing, especially if they contain high concentrations of a desirable product such as oils (e.g., *Brassica napus*, canola). Attractive small seeds or those that have special properties or novel appearance may also have a market as whole grains similar to sesame (*Sesamum indicum*), poppy (*Papaver somniferum*) or linseed (*Linum usitatissimum*).

Species exhibiting high overall fecundity and the capacity to self-fertilize are highly desirable. Most domesticated grain legumes are self-fertilizing with the exception of *P. coccineus*, *Vicia faba* and *Cajanus cajan*[31]. Some difficulties might occur with domesticating outcrossing species

due to the ability to outcross with their wild counterparts and to reintroduce undesirable traits. Species capable of self-fertilizing would be less problematic for future breeding. Annual species may have a greater overall fecundity, because their survival relies on producing viable seeds, but perennial species may be equally productive provided they flower and reproduce in their first year[5]. Many domesticated annual grain legumes have originated from a perennial life form, most likely because of the selection pressure for increasing seed yield[31].

Grain chemistry and nutritional qualities

Native legumes found to produce seeds with high concentrations of protein and/or oils/fats are clearly desirable. In addition, those with favorable amino acid or fatty acid profiles or the presence of unique compounds that can benefit human health may have a significant market as a health food. In most cases, little information is available on the nutritive qualities of native Australian legumes. On the other hand, a number of Australia's native legumes are known to possess potent bioactive compounds, some of which may be toxic (e.g., swainsonine and hydrogen cyanide (HCN)), but some of which have pharmaceutical functions or can provide human health benefits at the correct concentrations (e.g., furanocoumarins and phytoestrogens)[36,37]. Many cultivated grain legumes contain anti-nutritional compounds which have been lowered by breeding (e.g., alkaloids in lupins)[38].

Canavalia

The genus *Canavalia* consists of approximately 70 species mostly of tropical origin. Several species are legume grain crops of secondary importance, including common jackbean (*Canavalia ensiformis*), sword bean (*Canavila gladiata*) and *Canavalia cathartica*. Raw seeds of *Canavalia* contain a number of anti-nutritional factors including phenolics, tannins, saponins, concanavalin A, canavanine, cyanogenic glycosides and HCN[39,40]. *Canavalia* are famous for the presence of the lectin, concanavalin A which has commercial importance as a reagent in glycoprotein biochemistry and immunology[41,42]. Four species of *Canavalia* are found in Australia but none are endemic; *Canavalia rosea*, *Canavalia carthartica, Canavalia sericea* and *Canavalia papuana*. These are mostly found in tropical, coastal hinterland regions (Fig. 2a). While *C. rosea* is found further south than other species into the subtropics, it is mainly confined to coastal and high-rainfall areas (Fig. 2a). Because *Canavalia* match poorly with our target climatic regions, they are not considered further here, although they may have some potential as an adapted legume crop for the tropics. They possess large seeds and are a rich protein source[39,42].

Crotalaria

Crotalaria is a genus of herbaceous plants and woody shrubs commonly known as rattlepods because seeds become loose in the pod as they mature and rattle when the pod is shaken. Around 600 or more species of *Crotalaria* are described worldwide, mostly from the tropics with at least 500 species known from Africa; 19 species are native to Australia[43]. Some exotic species of *Crotalaria* have agronomic uses (e.g., *Crotalaria spectabilis*, *Crotalaria ochroleuca*, *Crotalaria longirostrata* and *Crotolaria juncea* (sunn hemp))[43].

The Australian native *Crotalaria* species are mainly found in tropical regions. Four species occur further south in the target region; *Crotalaria eremaea* (desert rattlepod), *Crotalaria mitchelli* (yellow rattlepod), *C. cunninghamii* (green birdflower or parrot pea) and *Crotalaria dissitiflora* (plains rattlepod) (Fig. 2b). *C. eremaea* and *C. cunninghamii* occur mainly on sandy or well-drained soils in low-rainfall regions of central Australia[44]. *C. mitchelli* occurs on sandy soils in the tropical and subtropical areas of the east coast with >500 mm mean annual rainfall[45]. *C. dissitiflora* occurs on heavy clay soils also in the subtropics and tropics although it occurs further inland and in lower-rainfall regions than *C. mitchelli*[45].

Crotalaria includes annual, biennial and perennial species that can range in form from herbs to shrubs (0.3–3 m high). The four species occurring in the target region have erect or ascending habits; *C. cunninghamii* is an erect perennial subshrub growing to 1 m or higher, *C. eremaea* is an erect subshrub 0.5–1 m high, *C. dissitiflora* is an erect-sprawling short-lived perennial <30 cm high and *C. mitchelli* is an erect—decumbent woody forb about 60 cm high[44]. All these species flower in winter–spring (*C. cunninghamii* sometimes in autumn) and are generally open pollinated by insects. *C. dissitiflora* has been observed to shed its leaves during winter[45]. A notable and advantageous characteristic of these species is that flowers and pods are borne at branch ends[46], which favors mechanical harvesting. Some *Crotalaria* shatter explosively, while pods of others are more stable and slower to shatter[46].

Some *Crotalaria* have large seeds (e.g., 38 mg in *C. cunninghamii*) (Table 1), while others are smaller (e.g., those of *C. dissitiflora* are only 2–3 mm long). Seeds are often smooth and vary in color (yellow in *C. dissitiflora*, greenish–gray in *C. mitchelli* and red–brown in *Crotalaria smithiana*). Due to its large seed size and substantial protein and oil content (Table 2), *C. cunninghamii* was previously identified as a species worthy of further investigation[16].

Toxic pyrrolizidine alkaloids are produced by some members of this genus and these can be poisonous to livestock[47], but whether these are present in seeds of the four species that occur in the target region is unknown. *C. dissitiflora* is suspected of poisoning livestock, but there is conflicting evidence[45]. Everist[47] suggests that the toxicity might be lost when plants are cut. *C. eremaea* is often eaten by sheep, suggesting low or no alkaloid problems and

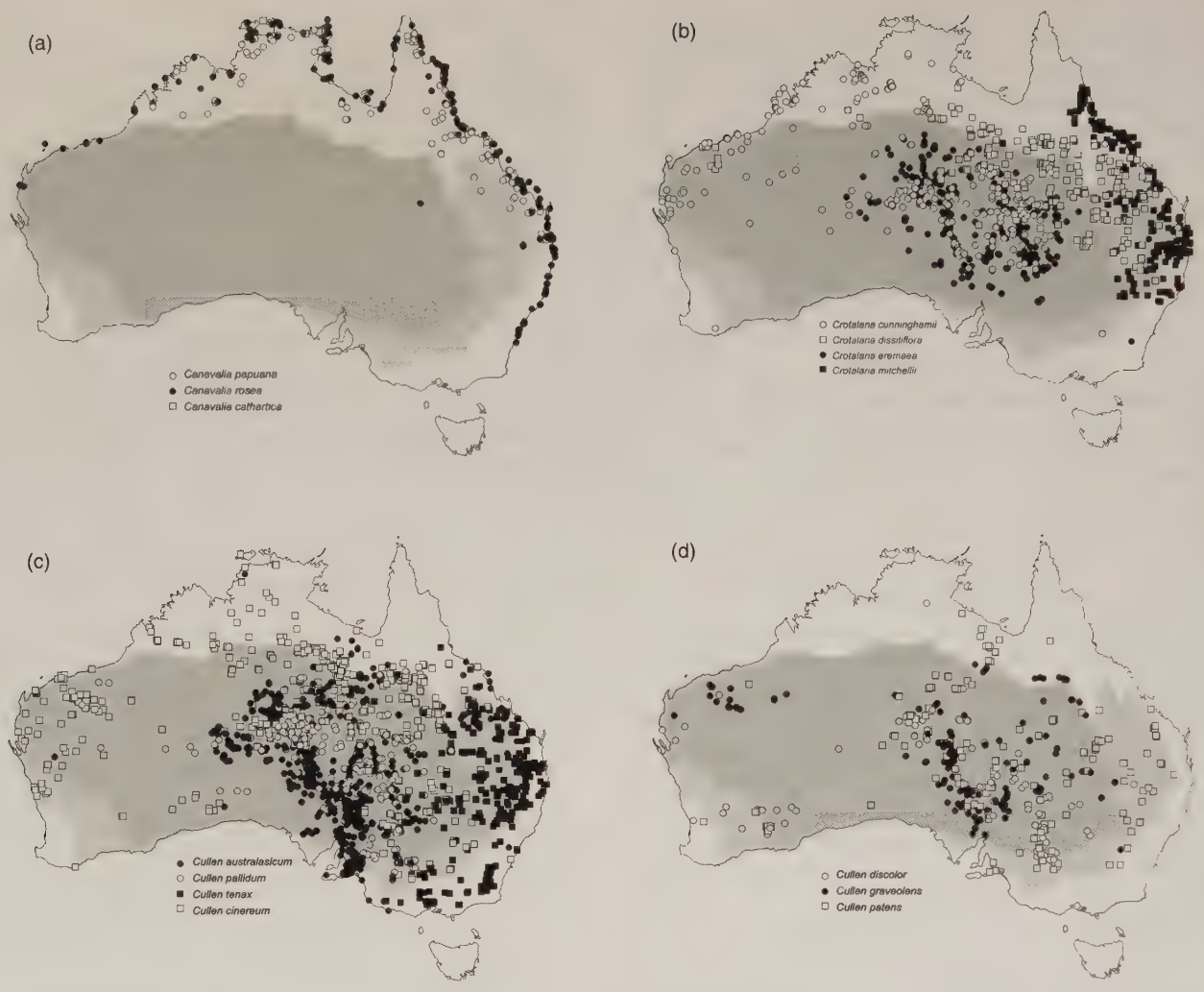

Figure 2. Distribution of a selection of widely distributed Australian native *Canavalia* (a), four native *Crotalaria* spp. (b) and *Cullen* spp. (c, d) mapped against targeted agro-climatic regions; semi-arid cropping zone (E2, E3 and E4)—light gray; and the arid interior (E6 and G)—dark gray (see Fig. 1). Data sourced from Australian Virtual Herbarium[28].

C. cunninghamii is reputedly edible by humans without any indication that prior treatment is necessary[44,48].

Overall, Australian *Crotalaria* seem to have a number of characteristics which suggest they warrant further investigation for their potential as grain crops. In particular, *C. cunninghamii* has a desirable growth habit, produces large seeds which contain high levels of protein and some oil, and does not seem to produce toxic alkaloids (Table 3). Little agronomic information was available on the other three species found in arid and semi-arid regions of Australia (i.e., *C. eremaea, C. mitchelli and C. dissitiflora*), but these may also warrant further investigation.

Cullen

The *Cullen* genus includes 32 species of which 25 are endemic to Australia[49]. It has been explored for forage plants in the past and again recently in Australia[11,50,51]. While no species of *Cullen* are used commercially, the closely related *Psoralea* genus includes one economically important plant native to India. *Psoralea corylifolia* seeds have medicinal properties, which are thought to be imparted due to their content of furanocoumarin, in particular psoralen.

Cullen in Australia is widely distributed across a range of climates from summer- to winter-dominant rainfall and the average annual rainfall of the distribution across species ranges from 200 to 1300 mm[51]. All species of *Cullen* occur within the target region and 12 of these species mainly occur in low-rainfall environments with an annual average rainfall $\leq$400 mm[51]. Of these species, *Cullen australasicum*, *Cullen graveolens*, *Cullen pallidum* and *Cullen discolor* mainly occurred in the lower-rainfall regions (Fig. 2c and 2d). *Cullen cinereum* has a slightly more tropical distribution than the other species; although, it is also found throughout the target zone (Fig 2c). *Cullen* species have been reported to have excellent drought tolerance where they have been evaluated as forage plants[11,52]. All species have a deep tap-root which may become woody in the perennial species. Roots of *Cullen patens*

Table 1. Seed size of Australian native herbaceous legumes. Means in brackets, where a range of material has been measured.

Species	Seed mass (mg)	Reference
Crotalaria cunninghamii	38.5	16
Cullen australasicum[1]	5.5	11
C. cinereum[1]	4.2	108
C. cinereum[1]	4.1	36
C. cinereum[1]	5.5	Unpublished data
C. graveolens[1]	2.3	Unpublished data
C. pallidum[1]	3.2–6.4 (4.8)	Unpublished data
C. patens[1]	8.4	108
C. patens[1]	2.8[2]	57
C. plumosum[1]	11.3	36
C. tenax[1]	4.4	Unpublished data
Glycine canescens	5.6	108
G. canescens	5.9–8.9	Unpublished data
G. clandestina	4.2	109
G. tomentella	5.0	57
G. latifolia	11.1	110
G. latifolia	6.6–12.5	69
Glycyrrhiza acanthocarpa	5.4	Unpublished data
Hardinbergia violacea	38.5	16
H. violacea	22	109
H. comptoniana	38.3–45.2	111
Indigofera colutea	1.1	108
I. linnaei	1.8	108
I. linnaei	1.9	Unpublished data
I. australis	5.2	16
Kennedia coccinea	8.8	16
K. coccinea	26.3	111
K. eximia	9.0	Unpublished data
K. nigricans	15.6	16
K. prorepens	12.4	112
K. prorepens	6.6	Unpublished data
K. prostrata	29.7	111
K. prostrata	31.9	86
K. prostrata	9.3–44.4	Unpublished data
K. rubicunda	24.4	109
Lotus australis	2.7	112
L. australis	1.3–1.9	Unpublished data
L. cruentis	1.8	88
Rhynchosia minima	11.8	57
R. minima	8.8–20.4 (12.1)	91
R. minima	9.4	108
R. minima	16.8	Unpublished data
Swainsona canescens	2.1	108
S. canescens	1.3	Unpublished data
S. colutoides	2.9	Unpublished data
S. kingii	2.6	Unpublished data
S. formosa	3.9	Unpublished data
S. purpurea	2.8	Unpublished data
S. swainsonoides	7.2	Unpublished data
Trigonella suavissima	1.0	Unpublished data
Vigna radiata ssp. *sublobata*	7.4–27.0 (13.4)	104
V. lanceolata	20–34	103
V. vexillata	8.1–17.7	113
V. vexillata	7.0–19.5 (11.1)	105

[1] Indicates whole fruit (pod + seed).
[2] Immature seeds harvested.

(syn. *Psoralea eriantha*) have been reported to penetrate to a depth of 4 m, and this was associated with the drought resistance of this species[53]. Another evident adaptation to drought is the dense coverings of glandular hairs on the leaves of some *Cullen* species (e.g., *C. pallidum* and *C. patens*). Strong soil-type associations are rare in many *Cullen* species (e.g., *C. australasicum*), but some species have particular preferences; for example, *C. tenax* seems to prefer heavy clay soils and *C. pallidum* is predominately found on deep sand dunes and sandy soils[45,49,51].

The Australian species of *Cullen* include shrubs, subshrubs and herbs and a number of them have a favorable growth habit and phenology, as outlined below. Nineteen species are herbaceous or semi-herbaceous, of which 16 are perennial or short-lived perennials. *C. graveolens*, *Cullen plumosum* and *Cullen walkingtonii* are annual or biennials[49]. Most Australian taxa bloom in the first year[49]. Flowering mainly occurs in spring, but indeterminate flowering continues throughout the year provided sufficient moisture is available[49,53]. In a glasshouse study, Bourgaud et al.[36] recorded that flowering occurs around 40 days after germination in *C. cinereum* (about 900 degree days) and around 60 days after germination in *C. plumosum* (1340 degree days). Flowering of *C. australasicum* and *C. patens* is controlled by day length according to Britten and De Lacy[54], with long-day treatments (i.e., <12–13 h dark) inducing flowering. They also found that genotypes vary in their response, indicating differences in phenological adaptations within these species. In *C. australasicum*, flowering and fruiting times are extremely variable in the first year, but with greater synchrony in the second year[11].

Many *Cullen* also seem to be capable of self-pollinating. Britten and Dundas[55] found that erect types in the *Psoralea patens* complex (i.e., *C. australasicum*) were 50–75% selfing, while the prostrate and semi-erect lines (i.e., *C. patens*) were outcrossing only. Bourgaud et al.[36] noted that *C. cinereum* and *C. plumosum* are capable of self-pollinating. Using microsatellite markers, Kroiss et al.[56] estimated the outcrossing rate in *C. australasicum* to be at least 3–13% and hybrids were formed with *C. pallidum*, but not *C. discolor* or *C. patens*.

A couple of studies have found *Cullen* to allocate significant resources to reproduction and produce useful amounts of seed. Bourgaud et al.[36] found seed yields up to 1.65 g plant^{-1} (47% of dry matter) from *C. cinereum* and 1.75 g plant^{-1} for *C. plumosum* (60% of dry matter). The higher yield from *C. plumosum* was due to the greater seed mass (11.3 mg), while the whole plant biomass was less than *C. cinereum*. The production of seeds from *C. tenax* has also been measured at 22 g plant^{-1} (4820 seeds) (Bennett, unpublished data). Kerridge and Skerman[53] recorded that the reproductive parts of *C. pallidum* made up 42% of plant biomass when the plants were left to grow for 12 weeks.

Cullen are characterized by indehiscent (non-shattering) fruits with the seeds adherent to the pericarp (pod). Fruit sizes of *Cullen* typically range from 4 to 6 mg, although

Table 2. Chemical composition of seeds of some native Australian legumes[16]. Seeds were obtained from a commercial native seed service and had presumably been collected from the wild.

Species	Crude protein[1] (%)	Fat (%)	Fatty acid composition (% of total fat)					
			16:0	18:0	18:1	18:2	18:3	P:S ratio[2]
Crotalaria cunninghamii	23.3	3.8	17.2	6.8	26.0	46.5	3.3	2.1
Hardenbergia violacea	21.0	8.1	12.1	5.1	23.2	55.9	5.0	3.4
Indigofera australis	18.8	2.8	17.6	3.8	26.3	45.6	6.2	2.4
Kennedia coccinea	27.4	3.0	12.3	7.0	29.2	43.9	6.4	2.6
Kennedia nigricans	23.9	9.1	14.9	6.5	30.2	41.0	4.4	2.1

[1] Protein was calculated as 5.7 × %N.
[2] Ratio of polyunsaturated to saturated fatty acids.

Table 3. Prioritization of species for further investigation as grain legume crops. Species with little information are not included (?—indicates where information is unknown).

Species	Distribution[1]	Life cycle[2]	Habit[3]	Seed size[4]	Flowers in first year	Pollination	Pod/seed retention	Other notable qualities/ information
Highest priority species for further investigation								
Cullen tenax	****	P	Sp, C	Small	Y	Selfing	Low	Aerial seed
Crotalaria cunninghamii	****	P	E	Large	?	?	?	Pods on branch ends
Glycine canescens	****	P	T	Mod.	Y	Selfing	Low	
Glycyrrhiza acanthocarpa	****	P	E, C	Mod.	?	?	High	Salt tolerance and pods easy to thresh
Kennedia prorepens	****	P	T	Mod.–Large	Y	Open	Low	
Rhynchosia minima	***	P	T–SE	Mod.–Large	?	Selfing	Variable	
Swainsona canescens	****	A/B	SE, Sp	Small	Y	Open	Mod-High	
Swainsona colutoides	***	A/B	E	Small	Y	Selfing	Mod, delayed	Good pod retention
Trigonella suavissima	****	A	E–SE	Small	Y	?	?	Waterlogging & potential salt tolerance
Moderate priority species with a number of suitable attributes								
Cullen australasicum	****	P	E	Mod.	Y	Open	Variable	
Cullen cinereum	***	A/B	E, Sp	Small–mod.	Y	Selfing	Variable	
Cullen graveolens	***	A/B	E–SE	Small	Y	?	?	
Cullen pallidum	***	P	Sp	Small–mod.	Y	Open, some selfing	Variable	
Glycine latifolia	**	P	T	Mod.	Y	?		Collected and selected as a forage
Glycine tabacina	**	P	T	Small–mod.	Y	?	Low	
Kennedia coccinea	*	P	P, T	Large	Y	?	?	
Indigofera australis	***	P	E, Sp	Mod.	?	?		
Swainsona formosa	****	A	SE, Sp	Small	Y	?	?	
Swainsona swainsonoides	***	P	Sp	Small	Y	Open	Low	
Species with some valuable attributes but some limitations								
Kennedia prostrata	**	P	P, T	Large	N	Open		
Kennedia nigricans	*	P	P, T	Large	?	Open		
Lotus cruentus	****	A	Sp, C	Small	Y	Selfing	Very low	

[1] Match between species distribution and targeted agro-climates; ****—highly favorable, ***—favorable, **—moderate, *—poor.
[2] P, perennial; A, annual; B, biennial.
[3] E, erect; SE, semi-erect; P, prostrate; T, twining/trailing; Sp, spreading; C, clumping/crown forming.
[4] Large, 10–20 mg; Mod., 5–10 mg; Small, < 5 mg.

fruits >8 mg have been measured in *C. patens* and *C. plumosum* (Table 1). Smaller fruits (2.8 mg) were found for *C. patens* by Silcock and Smith[57], but this included many immature seeds which probably reduced the average seed mass. The non-shattering nature of *Cullen* is advantageous for harvesting, but fruit retention on the plant is variable. Skerman[58] reports that ripe pods of *C. patens* drop to the ground and seed harvesting would need to be performed by suction. The pods of several species (e.g., *C. australasicum*, *C. patens*, *C. pallidum* and *C. discolor*) fall from the plant enclosed in the calyx, which can be very hairy[49]. This, and the adherence of the seed to its pod, also poses some complications about the ability to thresh the seed of *Cullen*, unless processing could utilize the whole fruit. Dear et al.[11] state that the seed of *C. australasicum* is easily threshed from the pod without damage. However, since the seed is completely adhered to the pod, it is likely that they were referring to the removal of the woolly calyx material.

No information was found on the protein or oil content of *Cullen* seed/fruit, but like other members of the Psoraleae family, Australian *Cullen* species are known to contain the furanocoumarins psoralen and angelicin[59–61]. Furanocoumarins are potent photosensitizing agents that may cause phototoxic reactions, but they are also pharmaceutically useful for the treatment of skin disorders such as psoriasis, vitiligo, leukoderma and leprosy[62]. The seeds of Australian *Cullen* species have been found to contain between 1000 and 8000 mg kg^{-1} dry weight (DW) of furanocoumarins (depending on species) and have been proposed as potential sources for pharmaceutical use[36,61,62]. *C. cinereum* (syn. *Psoralea cinerea*) and *C. plumosum* were identified with the highest levels of furanocoumarins, but they have also been measured in *Cullen lachnostachys* (syn. *Psoralea lachnostachys*) and *Cullen pustulatum* (syn. *Psoralea pustulata*) and are likely to exist in many other species. The fruits generally contain the highest concentration of furanocoumarins, up to 5500 ppm in *Cullen corylifolia* (native to India) and the majority (>70%) of this is found in the cotyledon of the fruit[60,63]. Vegetative material may also contain significant levels of furanocoumarins (up to 1600 ppm)[60,64], which may affect the health of grazing animals by inducing photodermatitis. However, furanocoumarins also play an important role in plant health by controlling pathogens and insect activity.

In addition to furanocoumarins, some *Psoralea* and *Cullen* species can also contain the flavonoid, daidzein, which is increasingly studied because of its activity in cancer prevention and treatment[65]. Daidzein has been found in the fruits of two Australian species, *C. cinereum* (8.2 mg g^{-1} DW) and *C. tenax* (27.5 mg g^{-1} DW) and was also present in their stems[61,65]. *C. patens* and *C. cinereum* were found to also contain lectins and trypsin inhibiting proteins[39].

A number of *Cullen* species warrant further investigation for potential as grain crops (Table 3), because they are able to produce large amounts of seed of moderate size, are self-compatible, have an erect growth habit, and the ability to grow and flower in their first year. High-priority species have a reputation for high seed production (e.g., *Cullen tenax* and *C. cinereum*) or display an annual life cycle (e.g., *C. graveolens*). Also an exciting attribute is the likely presence of furanocoumarins which may provide a pharmaceutical market for *Cullen* seed. However, the problem of separating the seed from the calyx is a significant issue and their market success would rely on uses that can utilize the whole fruit.

Desmodium

Desmodium, also known as tick-trefoils or tick clovers, is a large and taxonomically confusing genus containing about 300 species of which 21 species are native to Australia[43]. No *Desmodium* species are grown as grain crops, but some are cultivated as forage for livestock (e.g., *Desmodium intortum and Desmodium uncinatum*) and as living mulch or green manures.

Most Australian *Desmodium* occur in the tropics and subtropics and only three species are distributed within the target region; *Desmodium varians* (slender tick-trefoil), *Desmodium campylocaulon* (creeping tick-trefoil) and *Desmodium brachypodum* (large tick-trefoil) (Fig. 3a). *D. varians* occurs at the furthest south in the temperate regions of Australia, but is mainly found in moister regions. *D. varians* is a trailing or twining perennial that can flower all year round, although flowering is usually concentrated in the warmer months. *D. campylocaulon* and *D. brachypodum* are mainly found in the inland subtropics and tropics. Both are erect and twining long-lived perennial subshrubs growing up to 60–100 cm high, which flower from late spring to autumn[46]. All three species have a warm-season-dominant growth pattern and seem to prefer climates where rainfall is summer-dominant.

An advantageous characteristic of *Desmodium* species is that their reproductive racemes are at branch ends and in some species are held well above the foliage (e.g., *D. brachypodum*)[46]. *Desmodium* pods also do not split or dehisce at maturity, but they have a saw-like pod with segments that separate at maturity which enclose an individual seed (known as a loment) and are individually dispersed[46]. No information was found on the seed constituents or the presence of toxins or other bioactive compounds in the seed of Australian *Desmodium*, although some *Desmodium* species are known to contain alkaloids in their leaves.

Overall, we consider the *Desmodium* species to be of marginal interest because of the little information on the agronomic and seed attributes, and their tendency toward moister- and summer-dominant rainfall environments.

Glycine

Australia is the center of diversity for the *Glycine* genus, which contains the most important legume grain crop worldwide, soybean (*Glycine max*). The 23 *Glycine* species native to Australia make up the subgenus *Glycine*, while the cultivated *G. max* and its ancestor *Glycine soja* make up the

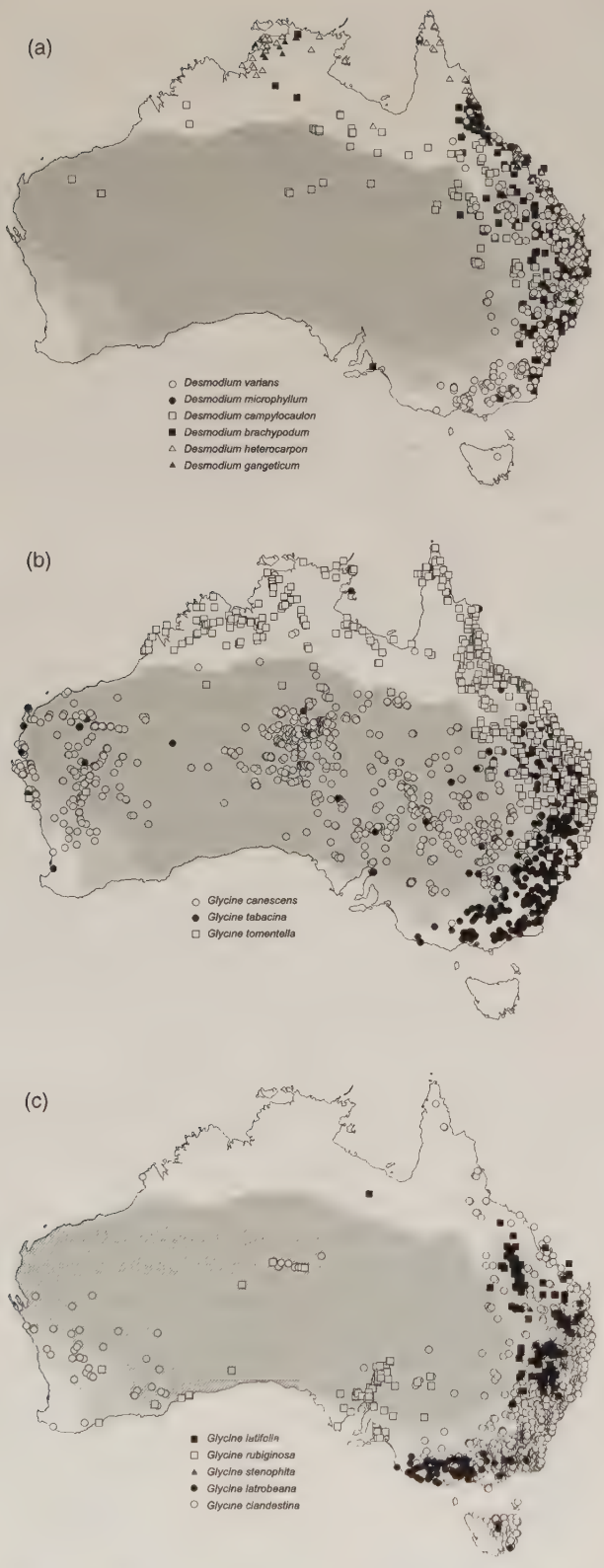

Figure 3. Distribution of Australian native *Desmodium* spp. (a) and *Glycine* spp. (b, c) mapped against targeted agro-climatic regions; semi-arid cropping zone (E2, E3 and E4)—light gray; and the arid interior (E6 and G)—dark gray (see Fig. 1). Data sourced from Australian Virtual Herbarium[28].

subgenus *Soja*, which originates in South-East Asia. Numerous attempts to hybridize wild *Glycine* and *G. max* have been made and have mainly been successful with tetraploid ($2n = 80$) types of *Glycine tomentella*[5]. Australian *Glycine* species have been investigated for beneficial traits for soybean improvement, such as drought tolerance[66], 2–4D resistance[67] and resistance to diseases (e.g., *Phakospora pachyrhizi*, soybean rust)[25,26,68]. *Glycine* are highly palatable to stock and have been investigated for their agronomic potential as pasture species, with one variety of *Glycine latifolia* commercially released in Australia[69].

Glycine species occur across Australia, with four species widely distributed: *Glycine canescens* (silky glycine), *Glycine tabacina* (variable glycine), *Glycine clandestina* (twining glycine) and *Glycine tomentella* (rusty glycine) (Fig. 3b and c). *G. canescens* had the most desirable distribution as it occurred across the targeted agro-climatic zones, in particular, within the arid interior (Fig. 3b). Young plants of *G. canescens* have been reported to have particularly good adaptation to low-P stress, partly due to a high seed P concentration[70]. *G. tomentella* occurs within targeted regions, mainly in the subtropical, subhumid climatic zone (i.e., E4), but its distribution indicates a tendency toward more tropical adaptation, and hence was considered less suitable (Fig. 3b). *G. tabacina* and *G. clandestina* occur predominantly in regions of eastern Australia with wetter climates and were found to a lesser extent within the target regions (Fig. 3b and c). Other evidence suggests that *G. tabacina* is better adapted to drier environments than *G. tomentella* due to its smaller leaflet size, the exhibition of paraheliotropism and its ability to maintain photosynthetic gas exchange and chlorophyll fluorescence at low water availability[66]. Within their distribution, *G. canescens* and *G. tomentella* are commonly found on sandy soils, *G. clandestina* on sandy red earths and *G. tabacina* is more suited to heavier and deeper soils[45]. Less widely distributed *Glycine* species that occur within the target regions include *G. latifolia* (subtropical regions) and *Glycine rubignosa*, while *Glycine latrobeana* was not suitable as its distribution is limited to cooler, moist environments of southeastern Australia (Fig. 3c).

All Australian *Glycine* are perennial twining herbs. Most are active and flower in the warmer months and usually in the first year after establishment[45]. *G. clandestina* flowers in spring to early summer, *G. tabacina* in summer and *G. tomentella* in spring and autumn. *G. canescens* flowers most of the year and is highly indeterminate[45]. Some accessions of *G. latifolia* grown in Queensland are exceptionally fast to flower, ranging from 13 to 59 days to first flower in the establishment year[69], suggesting that germplasm adapted to short growing seasons are available. In *G. tomentella*, Jones et al.[69] found flowering to be day length sensitive, with flowering inhibited at longer day lengths (>16 h), but flowering was initiated with shorter day lengths (<12 h). However, variability between accessions was found. Phenology of node appearance and flowering in

G. tomentella is also driven by thermal time, with flowering occurring after 60 days under warmer conditions (28/24°C day/night temperatures, i.e., 1560 degree days) and 75 days under cooler temperatures (24/20°C day/night, i.e., 1650 degree days)[71].

Seeds of wild *Glycine* species are typically moderate in size (5–10 mg). Measured seed weights are often between 4 and 6 mg for *G. canescens*, *G. clandestina* and *G. tomentella* (Table 1). *G. latifolia* has larger seeds (6.6–12.5 mg) (Table 1), with seed size of the released forage cultivar Capella being 12.5 mg[69]. *Glycine* seeds are oblong or ovoid, vary from smooth shiny to roughened dull seed coats and differ in color between species (*G. canescens*—olive-brown, *G. clandestina*—red–brown, *G. tabacina* and *G. tomentella*—purplish–black).

Surprisingly, no data on the seed composition of wild Australian native *Glycine* were found in the literature. Like soybean and *G. soja*, Australian native *Glycine* are known to produce isoflavones, although these have not been specifically measured in seeds. Taiwanese wild *Glycine* species including *G. tabacina* and *G. tomentella* were reported to have lower isoflavone concentrations in seeds compared to stems and roots[72]. Many of these are phytoestrogens have a range of health benefits and applications[37]. *G. canescens* and *G. latifolia* contain genistin, daidzein and coumestrol; *G. tabacina* contains quercetin and kaempterol; and apigenin was found in *G. tomentella*, *G. tabacina* and *G. falcata*[73]. Alkaloids have been reported in *Glycine sericea*[74], but these are generally not considered to be a problem in *Glycine*.

Overall, Australian native *Glycine* are of significant interest for further appraisal as a grain crop. They have attractive seeds of moderate size which potentially contain chemicals with pharmaceutical applications. The major constraint for most wild *Glycine* is their twining/trailing habit, which is not desirable in a crop plant. Of the *Glycine* species, we judge that *G. canescens* is the highest priority for further investigation because of its distribution in arid regions of Australia (Table 3). *G. latifolia*, because of its larger seeds and evidence of germplasm with quick maturity, also has a number of suitable attributes. More information is required on the seed chemistry and seed yield potential of many species of native Australian *Glycine*. Because of their close relationship and potential for hybridization with soybean, this information would also be useful for identifying novel or advantageous traits for soybean breeding.

Glycyrrhiza

Glycyrrhiza is a genus of about 18 species, which includes only one species native to Australia, *Glycyrrhiza acanthocarpa* (native liquorice and native lucerne). The genus is best known for liquorice, which is the product of the roots of *Glycyrrhiza glabra*, a species native to the Mediterranean region. Russian liquorice (*Glycyrrhiza echinata*) and Chinese liquorice (*Glycyrrhiza uralensis*) are also cultivated, the latter being important in traditional Chinese medicine.

G. acanthocarpa occurs from the semi-arid to arid fringe of southern Australia's cropping regions, thus appears well adapted to water-limited environments with a winter-dominant growing season (Fig 4a). It occurs in various habitats and soil types from sandy to clay soils, but is especially common on soils prone to flooding. It has been found to be reasonably tolerant of waterlogging and saline conditions (growth reduced to 59% of control under 120 mM of NaCl solution) (Rogers and Spokes, unpublished data), but performed poorly in a series of field experiments in waterlogging-prone sites due to poor establishment and poor biomass production[75].

G. acanthocarpa is an erect to semi-prostrate to ascending perennial subshrub growing 1 m high. It flowers from early spring through to late summer and produces single-seeded pods covered in hard bristles or prickles. Advantageously, these pods are indehiscent or tardily dehiscent, which means pods do not split at maturity, or if so, quite late[46]. Seeds of *G. acanthocarpa* are kidney-shaped and attractively colored, usually olive-green, mottled with black[46]. Seeds are quite small, being about 2.5 mm long and about 5 mg (Table 1). No documented information was found on seed yield, seed protein or oil content, or the presence of bioactive compounds or toxins in seeds. Other exotic *Glycyrrhiza* are known to possess a number of medically beneficial properties[76]; whether these active chemicals occur in the seeds of *G. acanthocarpa* is unknown.

Overall, we consider *G. acanthocarpa* to be worth further appraisal as a grain crop (Table 3). It has a suitable growth habit, its pods are indehiscent, it has moderate-sized attractive seeds and its distribution suggests a high suitability to Australia's more arid cropping regions. More information is required on the seed chemistry and seed yield potential of this species.

Hardenbergia

Hardenbergia is a genus of three species, all endemic to Australia. *H. violacea* (false sarsparilla, purple coral tree and happy wanderer) is widely grown as a hardy ornamental garden plant, with many cultivars available. *H. violacea* is a widespread species found in many habitats, although it generally tends toward higher-rainfall regions (Fig. 4a). *Hardenbergia comptoniana* is only found in southwestern Australia and mainly around the wetter coastal regions with mean rainfall greater than 700 mm per annum (Fig. 4a). All species are climbing vines, but sometimes can assume a subshrub form. Pods are dehiscent and in some cases these can be explosive[77]. *Hardenbergia* are large-seeded (22–45 mg) (Table 1) and can contain favorable concentrations of crude protein and oils[16] (Table 2). Despite these positive attributes, we consider *Hardenbergia* to be of marginal interest as they are primarily adapted to moist environments and their twining

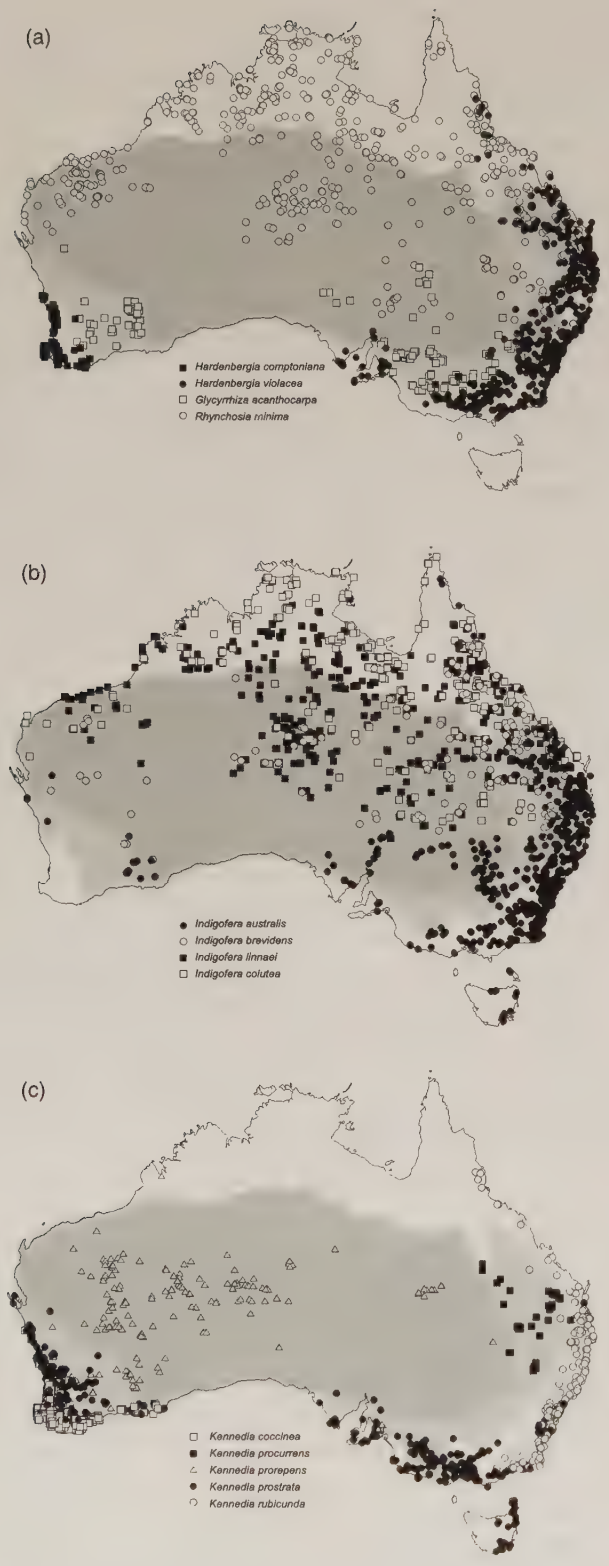

Figure 4. Australian distribution of native *Rhyncosia*, *Glycyrrhiza* and *Hardenbergia* spp. (a), *Indigofera* spp. (b) and *Kennedia* spp. (c) mapped against targeted agro-climatic regions; semi-arid cropping zone (E2, E3 and E4)—light gray; and the arid interior (E6 and G)—dark gray (see Fig. 1). Data sourced from Australian Virtual Herbarium[28].

growth habit would be a further obstacle to their development as a grain crop.

Indigofera

Indigofera is a large genus of about 700 species of which 33 are native to Australia[43]. They occur throughout the tropical and subtropical regions of the world, with a few species reaching the temperate zone. These are mostly shrubs, although some are herbaceous, and a few can become small trees up to 5–6 m tall. Most species are dry-season or winter deciduous. Several of the exotic species (especially *Indigofera tinctoria* and *Indigofera suffruticosa*) are commercially grown to produce the dye, indigo.

Most Australian *Indigofera* occur principally in the tropics and only *Indigofera australis* (Austral indigo), *Indigofera brevidens* (desert indigo), *Indigofera colutea* (rusty indigo) and *Indigofera linnaei* (Birdsville indigo) occur within our target region to any significant extent (Fig. 4b). *I. australis* occurs further south than the other three species and is found throughout the winter-dominant rainfall regions (Fig. 4b). *I. australis* and *I. brevidens* prefer sandy soils from granite or sandstone origin and commonly occur on granite plains and outcrops and river flats[78].

These four *Indigofera* species all have favorable growth habits and winter–spring growth patterns. *I. australis* is a highly variable species, but is often an erect spreading shrub with flexible stems growing up to 2.5 m tall[46]. It flowers in winter to early spring and flowers and pods are held in leaf axils, distributed along the stem. *I. brevidens* and *I. colutea* are both smaller perennial subshrubs growing 0.4–1 m high, although *I. brevidens* is often spiny which may limit its suitability for agriculture[46]. *I. colutea* flowers in autumn, while *I. brevidens* flowers from spring to early summer[45].

Indigofera seed are small with a squarish, blunt shape and the seed coat is often spotted. Seeds of *I. australis* appear to be larger (about 5 mg) than those of *I. colutea* and *I. linnaei* (< 2 mg) (Table 1). *I. australis* seeds have been found to contain 19% crude protein and 2.8% oils, which was lower than other native legumes tested[16] (Table 2). *Indigofera* are also known to contain a variety of anti-nutritional or bioactive compounds such as indospicine and 3-nitropropanoic acid[39,78]. *I. linnaei* is known to contain indospicine in its leaves and seeds which can cause a toxic condition in horses but not cattle[79]. *I. australis* can also contain HCN and is suspected of being toxic to grazing livestock while flowering[45]. Despite the presence of anti-nutritional factors, a variety of *Indigofera* species did not reduce the growth rate of rats fed their seed or leaves[78], indicating their potential as animal feed. Some exotic species of *Indigofera* actually have analgesic properties and have been used historically as anti-inflammatories and for pain alleviation (e.g., *Indigofera articulata*, *Indigofera oblongifolia, I. suffruticosa* and *Indigofera aspalthoides*)[80]. Whether these qualities are present in Australian *Indigofera*

or if the active compounds are present in the seeds is unknown.

Of Australia's *Indigofera* species, *I. australis* appears to have the greatest potential for temperate agriculture due to its larger seeds and more southern distribution, although it has been found to have lower protein and fat content than some other native legumes (Table 3). Seeds of *Indigofera* may also offer some novel medicinal uses, although their chemistry still remains to be explored.

Kennedia

Kennedia have long been identified as legumes with agricultural potential[8]. In particular, *Kennedia* from low-rainfall wheatbelt areas of Australia have been suggested as possible forage plants (e.g., *Kennedia prostrata*, *Kennedia stirlingii* and *Kennedia prorepens*)[81–83]. Yet, no species have been domesticated, although a number of them are grown as ornamentals.

The *Kennedia* genus contains 15 species all of which are endemic to Australia[43]. The most widely distributed species are *K. prostrata*, found across southern Australia but mainly in moister regions, and *K. prorepens*, found throughout the arid regions of central Australia (Fig. 4c). There are nine *Kennedia* species endemic to southwestern Australia, eight of these species have quite localized distributions mainly along the southern coast or higher rainfall coastal regions outside the target region (i.e., *K. nigricans, Kennedia glabrata, Kennedia beckxiana, Kennedia carinata, Kennedia eximia, Kennedia stirlingii, Kennedia macrophylla and Kennedia microphylla*) (not shown). The one more widely distributed western Australian species, *Kennedia coccinea*, is predominantly found in the high-rainfall regions, although it occurs to a lesser extent in the target regions (Fig. 4c). Silsbury and Brittan[84] observed that the distribution of *K. carinata* corresponded to regions with a >7-month growing season and *K. coccinea* to regions with a 6-month growing season, while *K. prostrata* was found in drier regions with a shorter growing season (5 months). There are three *Kennedia* species only found in eastern Australia; *Kennedia rubicunda* has a wide distribution but mainly occurs in higher-rainfall environments along the east coast (Fig. 4c); *Kennedia procurrens* is found within the target region, although almost entirely within the subtropical subhumid region (E4) (Fig. 4c); and *Kennedia retrorsa* has a small distribution outside the target region (not shown). *Kennedia* species are mainly found in woodland or forest habitats and have a preference for light, well-drained soils. This adaptation to light-textured soils also suggests that they have some tolerance of drought and poor soil fertility. Two recent studies show that *K. prostrata* and *K. prorepens* seedlings grew better than some other perennial legumes under low phosphorus stress, partly due to high seed phosphorus concentrations[70]. However, these same studies show that these two species are particularly intolerant of high mineral soil phosphorus concentrations and thus would be suited only to low input agriculture on poor soils. A further problem with *Kennedia* is a high degree of seed dormancy which has proved difficult to overcome.

All *Kennedia* are evergreen prostrate or climbing perennials. They are herbaceous but often have woody stems at their base. Most species display indeterminate flowering from late winter into early summer with pod maturity reached about 1 month later. *K. prorepens* flower throughout winter beginning in autumn until late spring. Flowers are open pollinated by insects or birds. Elongated pea-like pods contain 4–50 seeds. Mature pods are dehiscent, but valves do not twist at maturity. One study has reported seed production of 200 kg ha^{-1} from *K. prostrata* at the onset of November at Merredin in the Western Australian wheatbelt[82]. This was about 10% of the total shoot biomass at this time. However, flowering and seed production did not occur until the second growing season for *K. prostrata*[82]. This is commonly recognized in *K. prostrata*, while other *Kennedia* species (e.g., *K. prorepens* and *K. coccinea*) flower in their first year.

Kennedia have quite large seeds compared to many of the other native legumes, with many species having seeds >10 mg. Seeds up to 44 mg have been measured in *K. prostrata*, but the seed size in this and other species seems to be highly variable (Table 1). The chemical composition of seeds of some *Kennedia* species has shown them to possess high levels of protein and favorable fatty acids. *K. coccinea* and *K. nigricans* were found to have >24% protein and fatty acids consisted of 20% saturated, 30% monounsaturated and 50% polyunsaturated fats. *K. nigricans* (9%) had higher total fat/oil content than in *K. coccinea* (3%)[16] (Table 2). *K. prostrata* seeds have also been found to contain >22% protein (N% × 5.7), which was concentrated in the embryo and cotyledon[85]. The embryo and cotyledons made up only 23.7% of the seed weight compared to the testa (seed coat) which made up 75% of the seed weight and contained over 30% of its N and P[86]. This contrasts strongly with many domesticated grain legumes, where the testa consists of a small proportion of the seed's dry matter (e.g., *Pisum* 10.4% and *Lupinus* 12.7–33.7%) and contains < 5% of the seed's N and P[85,87]. Hence, it appears that significant gains could be made in improving the total protein yield from *Kennedia* seed by selecting for thinner seed coat.

The thick testa in *K. prostrata* probably imparts the dormancy and longevity required for seeds to persist over many years. High levels of seed dormancy have also been seen in other *Kennedia* (over 95% seeds were dormant at maturity in *K. rubicunda*), which can cause problems for uniform and reliable germination that would be required in a crop. Selection for soft, thin seed coats in cultivated grain legumes has removed the dormancy imparted by a thick testa, and has enabled nutrients which might have otherwise gone to this structure to be directed to the embryo[31].

Although no major toxicity problems have been documented with *Kennedia*, Rivett et al.[16] found *K. nigricans* and *K. coccinea* seeds to contain significant concentrations

of canavanine, 8.1 and 6.0 mol%, respectively. However, the presence of canavanine in some of these seeds should not prove an obstacle to their food use since the apparent toxicity of this compound is low.

Overall, *Kennedia* are an interesting genus to consider further as a grain crop. They have large seeds (up to 45 mg) with advantageous nutritional qualities, some species produce copious seeds in the first year. As with *Glycine*, a major constraint is their twining/trailing habit which is not favorable in a crop plant. Of the *Kennedia* species, *K. prorepens* has the most desirable distribution and appears well adapted to arid environments and hence was prioritized for further investigation (Table 3). Germplasm of *K. prostrata* also has some desirable adaptations to challenging environments, but its inability to flower and set seed in its first year is a major constraint (Table 3).

Lotus

The *Lotus* genus (bird's foot trefoils and deer vetches) includes between 70 and 150 species (depending on author). Several species are cultivated as forage plants in many regions of the world, but not as a grain crops (e.g., *Lotus corniculatus*, *Lotus pedunculatus* and *Lotus glaber*). The genus is large, but only two species are native to Australia, *Lotus australis* and *Lotus cruentus*. Both *L. australis* and *L. cruentus* are found in the target region throughout southern and inland Australia, but of the two, *L. cruentus* may have greater adaptation to the lower-rainfall regions (Fig. 5a). Both species are found on a wide range of soil types and habitats and are considered to be drought resistant[45].

Both Australian *Lotus* species can perenniate and flower in their first year, although *L. cruentus* often acts as an annual and produces copious seeds[88]. *L. australis* has an erect-ascending habit growing up to 60 cm in height, while *L. cruentus* is more prostrate to ascending[46]. Flowering can occur all year round, but mainly occurs in spring with maturity in early to mid summer[46]. Plants are pollinated by insects, commonly bees, although *L. cruentus* appears to be reasonably self-compatible (Richard Bennett, unpublished data).

One major limitation of *Lotus* species for grain production is the loss of seed due to their continuous flowering and high propensity for the pod to shatter at maturity. Seed shattering (dehiscence) is a major problem for seed production in domesticated *Lotus* species used as forage plants and seed losses can vary between 5 and 88%[33]. *Lotus* species are generally small seeded, with seeds weighing between 1.3 and 2.7 g (Table 1). Seed are often smooth, very round and brown colored with a mottled appearance. The content of protein, oils or other compounds in the seed from *Lotus* species is unknown. Both Australian *Lotus* species contain HCN in their shoots, which is associated with numerous cases of poisoning in cattle and sheep[39,45]. However, significant variability in HCN content has been identified in *L. australis*, enabling genotypes with low HCN

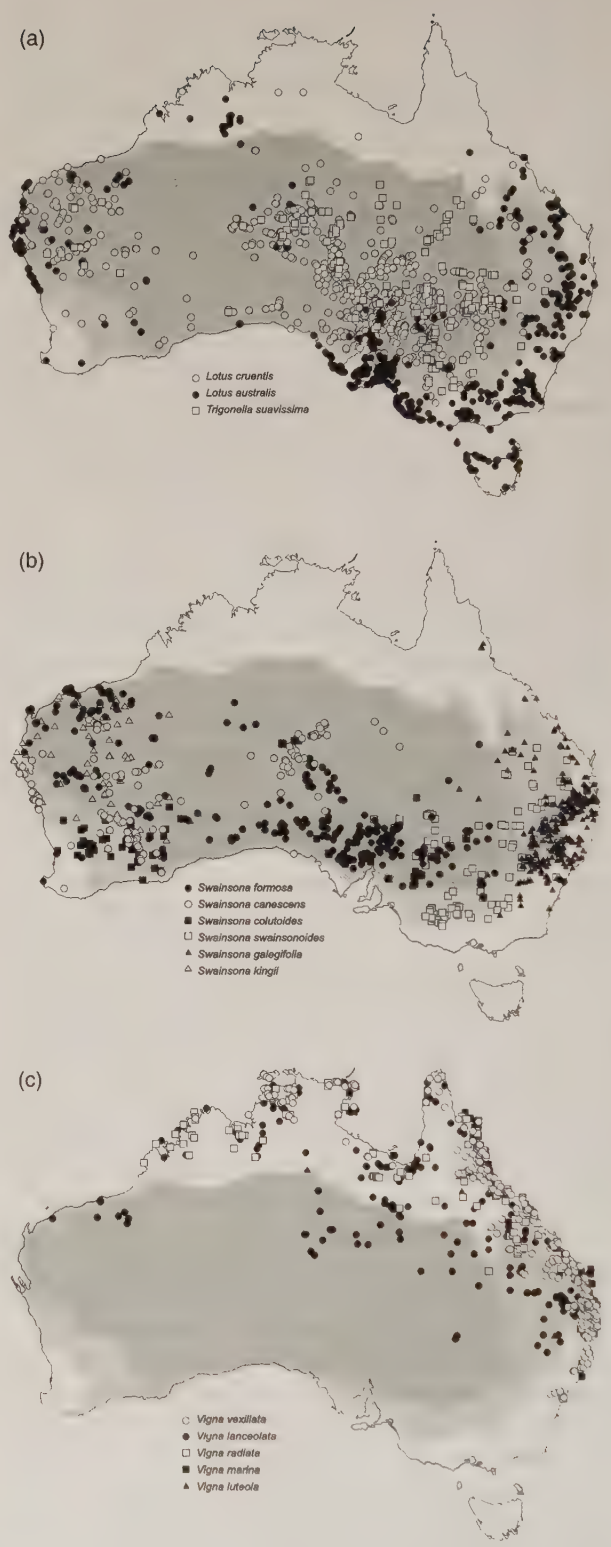

Figure 5. Distribution of Australian native *Lotus* and *Trigonella* spp. (a), a selection of widely distributed *Swainsona* spp. (b) and native *Vigna* spp. (c) mapped against targeted agro-climatic regions; semi-arid cropping zone (E2, E3 and E4)—light gray; and the arid interior (E6 and G)—dark gray (see Fig. 1). Data sourced from Australian Virtual Herbarium[28].

to be selected and bred[89]. Highest concentrations of HCN are found in the leaves and flowers; concentrations are much lower in the seeds and pods and decrease as pods mature[90]. Thus, HCN is unlikely to be a major difficulty in seeds of *Lotus* species and could actually be advantageous in vegetative parts to provide protection from insect herbivory, while the seed remains palatable.

Australian *Lotus* species have attracted interest as potential forage legumes for low-rainfall environments[89], but they seem less well suited as grain crops. They have quite small seeds, and their unappealing appearance would limit their novelty as a whole-seed product. Their propensity to shatter is a major agronomic problem and the lack of interest in using more domesticated *Lotus* species for grain production indicates that these species have limited suitability as grain crops (Table 3).

Rhynchosia

Rhynchosia includes more than 200, mostly tropical, species, with six species native to Australia. Several species in the genus are commonly called rosary bean because of their attractive red, blue, black, mottled or bicolored seeds. The pantropical species *Rhynchosia minima* is highly variable and has four varieties described in Australia [var. *amaliae*, *australis* (= *eurycarpa*), *minima* and *tomentosa*]. *R. minima* has previously been investigated as a potential forage plant and with many ecotypes that vary in their adaptation and growth characteristics there is significant opportunity to exploit this species[91].

Most Australian *Rhynchosia* are restricted to subtropical and tropical regions of Australia, but the most widespread species, *R. minima* (snout bean), is also found across the arid regions of central Australia and commonly within the target region (Fig. 4a). *R. minima* is found in a variety of habitats but most often on self-mulching heavy clay soils[46,91]. However, it has been collected from sands and sandy loams[91]. It is regarded as a hardy plant and tolerant of drought.

R. minima is a slender climbing or trailing perennial herb. It germinates on summer rains and flowers during spring–summer and produces abundance of seed[46,91]. Days for flowering vary from 43 to 142[91]. Pod indehiscence was found in most accessions of *Rhynchosia*, but some accessions do retain seeds longer than others[91].

Seeds of *R. minima* are reasonably large, kidney-shaped and grayish, brown or black and often mottled. The seed size may vary substantially, ranging from 8.8 to 20.4 mg[91]. There is no information on the concentrations of protein or oils in *R. minima* seed, but they have been found to contain some chemicals of pharmaceutical interest including prodelphinidin (antibiotic), gallic and protocatechuic acid (antiasthmatic and antioxidant)[6,80].

Overall, *R. minima* warrants further appraisal as a grain crop (Table 3). It has large attractive seeds and is regarded as a productive seed producer. Significant variability exists in important agronomic attributes such as days to flowering, pod indehiscence and seed size, providing the potential to identify and select desirable genotypes to improve grain production. Its distribution suggests that it is tolerant of water-limited environments, but its preference for heavy clay soils restricts its applicability in some regions.

Swainsona

Swainsona includes 85 species of which 84 are endemic to Australia. The best known of these species is *Swainsona formosa* (Sturt's desert pea), which is grown as an ornamental flowering plant, but little is known about most of these species. *Swainsona* are generally found throughout the arid interior of Australia with most occurring within our target region. Many species are not widely distributed, but the more widely distributed species include *S. formosa, Swainsona canescens*, *Swainsona colutoides* and *Swainsona swainsonoides* (Fig. 5b). Many species also exhibit characteristics of plants adapted to dry environments such as hairy leaves and branches, and a deep tap root.

Swainsona includes plants with annual, biennial and perennial life cycles and most could be described as small subshrubs that range from prostrate to semierect[92]. At least a few species are winter growing which flower and set seed in spring (e.g., *S. canescens*). Most species seem to be predominantly open pollinated by insects or birds[92], but some have a degree of self-compatibility. A few species are known to exhibit exceptional fecundity, for example, well-grown plants of *S. canescens* are capable of setting approximately 80,000 seeds (Bennett, unpublished data). Generally, the genus is described as dehiscent, but a number of species are known to be indehiscent or tardily indehiscent (e.g., *S. canescens, S. colutoides, Swainsona pyrophila* and *Swainsona fraseri*), where pods senesce with seeds are still enclosed. Seeds of *Swainsona* are usually small (< 3 mg) and kidney-shaped. However, *S. swainsonoides* appears to have larger seeds (>7 mg) than other species (Table 1). Seeds usually have hard seed coats, which induce dormancy.

Aborigines ate at least one *Swainsona* species, *Swainsona galegafolia* (Darling pea), which was eaten green and has a similar taste to the common garden pea[93]. Its green seed (69% moisture content) contains 31% protein, 33% carbohydrate, 26% fiber and 6% fat (on a dry matter basis)[93]. However, while 64% of the seed is edible, no information about the inedible component was provided. No information on the constituents of seed of other *Swainsona* was found.

Swainsona also gives its name to the toxic alkaloid swainsonine[39]; while this is poisonous to livestock, its effect on humans is unknown. Aplin and Cannon[74] report that the concentration of alkaloids in general (not only swainsonine) in the vegetative material of other *Swainsona* species was high in *Swainsona rostellata*, moderate in *Swainsona campestris*, *S. canescens*, *Swainsona incei*, *Swainsona stipularis* and low in *Swainsona cyclocarpa*, *Swainsona flavicarinata* and *Swainsona occidentalis*.

Species reputedly or proven to be poisonous when grazed by livestock include *Swainsona galegifolia*, *Swainsona sejuncta*, *Swainsona greyana*, *Swainsona lessertiifolia*, *Swainsona luteola*, *Swainsona microphylla*, *Swainsona oroboides* and *Swainsona procumbens*[94]. Seeds of *S. galegifolia* and *S. sejuncta* contain 2900 and 1700 mg kg^{-1} of swainsonine, respectively[27]. There are few data on seed swainsonine concentration in other *Swainsona* species, but it would be expected to be negligible in species with low concentrations in vegetative material. For example, the swainsonine concentration in the stems or leaves of *S. galegifolia* (up to 7500 mg kg^{-1}) and *S. sejuncta* (up to 5200 mg kg^{-1}) is approximately 2.5 times the concentration in the seeds[27]. Thus species such as *S. formosa*, which have low concentrations of swainsonine in leaves (70 mg kg^{-1}) and flowers (210–490 mg kg^{-1}), may have very low concentrations in seeds[27].

Despite the lack of information on many *Swainsona* species, a number of them have characteristics which suggest that they are worthy of further investigation for their grain production potential (Table 3). In particular, *S. canescens* and *S. colutoides* are high-seed-producing species, which have delayed dehiscence, an erect growth habit and are not reported to contain high concentrations of swainsonine. Being an annual species with low risk of swainsonine problems, *S. formosa* may also be of further interest. Some other widely distributed *Swainsona* species (*S. swainsonoides*, *Swainsona purpurea* and *Swainsona kingii*) may also have potential, but lack information.

Trigonella

Of the 80 species in the genus *Trigonella*, *Trigonella suavissima* (sweet fenugreek) is the only native of Australia[43]. This species has been investigated for its potential as a forage plant[95]. Several exotic *Trigonella* species are important for culinary, nutritional or medical reasons[96]. The most widely used is fenugreek (*Trigonella feonum-graecum*), which is cultivated throughout semi-arid regions of the world as an alternative multipurpose crop that can be grown for grain, forage or green manure[97,98].

T. suavissima is a winter-growing annual or ephemeral, flowering between autumn and spring[46]. It occurs throughout inland arid environments in central Australia, where it is typically found on heavy clay soils of river banks, floodplains and depressions[45] (Fig. 5a). It is rarely found on sandy soils[45]. It is particularly prevalent in inland Australia after winter–spring rains or cool-season floods, forming dense swards on flood plains. Thus, while it occurs in arid environments its ephemeral life cycle allows it to avoid severe water stress rather than tolerate water deficit. *T. suavissima* has also shown good tolerance of salinity compared to other native and exotic legumes, with a growth of 106% of control at 40 mM NaCl concentration[99].

T. sauvissima has a desirable growth habit, being decumbent to ascending and reaching 50 cm in height[46]. Few agronomic data are available on the seed production potential of *T. sauvissima*, yet it is reputed to have a high level of fecundity[45]. Collected accessions of the species have flowered between 111 and 118 days after sowing, but because of its ephemeral life cyle in arid climates, it is likely that earlier flowering material exists. It is commonly pollinated by insects, but its self-compatibility is unknown[100]. A favorable attribute of *T. sauvissima* is that it can be indehiscent or tardily dehiscent, yet fruits are often shed from plants at maturity[92,100].

The seed of one tested accession of *T. suavissima* is small (1 mg, Table 1), substantially smaller than its grain legume relative, fenugreek (9–22 mg)[97]. The small seeds of *T. suavissima* may limit its yield potential as a grain crop. However, it could have been used as a multipurpose pasture and crop species (as for fenugreek), as it is regarded as a valuable and nutritious fodder source where it grows naturally[95]. There are no published studies of seed chemical composition or the presence of bioactive compounds in *T. suavissima.* Fenugreek contains a number of bioactive chemicals and has beneficial medicinal and nutritional qualities[101]. The presence of these qualities in *T. suavissima* is worth exploring.

Overall, *T. suavissima* is deserving of further appraisal as a grain crop (Table 3). It has a suitable growth habit and a number of desirable agronomic attributes, but in particular its distribution in arid environments suggests an ability to avoid or tolerate water stress. Its seeds potentially contain chemicals with pharmaceutical applications. The major limitation appears to be small seed size, warranting exploration for germplasm with greater seed size. More information is required on the seed chemistry and seed yield potential of this species.

Vigna

The *Vigna* genus contains a number of species that are widely grown as grain legumes throughout the world (e.g., mung bean (*Vigna radiata*), azuki bean (*Vigna angularis*) and cowpea (*Vigna unguiculata*)) and some secondary grain legumes (e.g., *Vigna acontifolia* (moth bean), *Vigna lanceolata* (pencil yam), *Vigna mungo* (urad bean, black gram), *Vigna subterranea* (Bambara groundnut), *Vigna umbellata* (rice bean) and *Vigna vexillata* (zombi pea))[98]. Five species of *Vigna* are indigenous to Australia and one is endemic (*V. lanceolata*)[102]. *Vigna radiata* ssp. *sublobata* is the putative progenitor to the cultivated mungbean (*V. radiata*) and is a native of Australia[43].

Australian *Vigna* species are predominately tropical species or are mainly found in higher-rainfall environments (Fig. 5c). *V. lanceolata* is the only species that occurs to any extent in our target region. It is a highly diverse species with a number of genotypes that exhibit significant variation in important agronomic traits (e.g., seed yield, days to flowering and frost tolerance)[103]. The key differences in agronomic traits between native *Vigna* and modern cultivars are longer time to flowering and maturity, smaller seed size, higher levels of hardseededness, a more prostrate

and twining habit and a lower seed yield and harvest index[104–106]. Overall, Australian *Vigna* are of secondary interest to us because of their predominantly tropical distribution and others have previously investigated their agronomic potential[104–106].

Conclusion

Australia has a diverse flora of herbaceous legumes and their agricultural potential and, especially, their potential to produce grain products has been little assessed. For many species, data are sparse and must also be considered with caution because of the likelihood that past studies have not adequately captured species' variability. Nevertheless, many species possess characteristics that would be useful in marginal grain growing environments due to their adaptation to arid and semi-arid climates and, sometimes, infertile soils. A major challenge for a number of species (e.g., *Glycine, Kennedia* and *Rhynchosia*) is their twining growth habit. However, this was the case in many of the progenitors of modern legume grain crops (e.g., *Glycine*, *Vigna*, *Phaseolus*, *Pisum* and *Arachis*)[31]. Similarly, substantial increases in seed size and the removal of seed dormancy mechanisms have previously been achieved through plant breeding, and so while many Australian native species have small seeds, there is a potential to increase seed size. Similarly, seeds of many undomesticated legumes are likely to have a high proportion of seed coat, as seen in *K. prostrata*[86], which if reduced could increase protein yield and reduce problems with hardseededness. Little information exists on the chemical constituents of many native Australian legumes, but some have a potential market because they possess attractive seeds (especially small-seeded species, e.g., *Glycine* and *Glycyrrhiza*) or because they possess bioactive compounds with prospects for use as natural medicines (e.g., *Glycine, Cullen, Trigonella* and *Indigofera*). While the germplasm of native legumes is currently stored in Australian Genetic Resource Centres[107], it is likely that these collections do not come close to fully representing the diversity present in natural populations and any serious attempt at domestication of most native legumes would need to commence with a comprehensive collection of wild germplasm[51].

This paper identifies a number of species with the greatest immediate potential to be developed as alternative grain legumes; however, additional basic information on the seed constituents, phenology, breeding system and reproductive potential of these species is required to narrow the list further. This is especially necessary in genera where little current data exist (e.g., *Swainsona, Glycyrrhiza* and *Crotalaria*). This work has been initiated and some preliminary studies will be reported in a forthcoming paper. Once two or three most promising species are identified, a preliminary selection and breeding program could commence to begin the domestication process. This process could commence with a—perhaps more limited—germplasm acquisition program, but before significant gains could be made, more substantial germplasm acquisition and characterization activities would be needed. Concurrently, evidence on the potential applications and market niche for grain from these species would be required. Ongoing collaboration with the food and/or nutraceutical industry would help this process. In addition, agronomic and physiological research should focus on confirming adaptive characteristics and agronomic suitability and help to focus future breeding priorities.

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Book Review

Anticancer: A New Way of Life, 2nd edition. By David Servan-Schreiber. 2009. Viking Penguin, London. ISBN 978-0-670-02164-2.

While searching for effective ways to support my partner in his recovery from prostate cancer, I read the above book. What an eye-opener it was! Written by a high-flying medic whose research project almost 20 years ago caused his cancerous brain tumor to serendipitously show up at a very early stage, the book contains some very significant information for those involved in food production and farming, whether at policy, research, academic, administration or production levels.

The author appears to remain rooted in the conventional scientific mind-set, i.e., 'if it's not in a refereed journal it's not scientific' medical approach to cancer. However, I suspect that his position may be protective coloration as he still practices clinical psychiatry, and conventional medicine appears not to take too kindly, particularly in USA, to challenges to its supremacy or its worldview. And so he synthesized his gleanings from reviews of the scientific literature ranging from agriculture, oncology, psychoneuroimmunology (PNI), food and nutrition, molecular biology and ecology, along with his own clinical experience and his personal experience as a cancer survivor, into this thoroughly engaging and informative book. In his own words, he tells 'the story of how he changed from a scientist–researcher, completely ignorant of the body's natural defenses, to a physician who relies above all on these natural mechanisms'.

The author presents an overview of knowledge of the mechanisms of cancer and how it has given rise to his view of four new approaches to the disease as follows:

1. Guarding the body against imbalances in our environment that have developed since 1940 and which promote the current cancer epidemic.
2. Adjusting the diet so as to cut back on cancer promoters and include the greatest number of phytochemical components that actively fight tumors.
3. Understanding and healing the psychological wounds that feed biological mechanisms at work in cancer.
4. Creating a relationship with our bodies that stimulates the immune system and reduces the inflammation that makes tumors grow.

Considering that food and its production are the focus of this journal, this review considers some of the implications of 1, 2 and 4 above. 1940 as a watershed year matches seismic changes in the industrialized world: synthetic chemical production, new methods of farming involving synthetic fertilizers, insecticides and herbicides, new farming practices that affected soil and biodiversity and new methods of food processing. New varieties of food and feed plants were developed with more attention paid to increasing production through matching agricultural tools and practices rather than focusing on nutritional needs of animals in the human food chain or of humans themselves. Some of the impacts are as simple as polluting the soil and water with carcinogenic products, some involve polluting food itself and others involve contaminating farm workers and negatively affecting their health and the health of their offspring through teratogenic effects. But groundwater pollution is never a simple matter, especially when it may end up bioaccumulating in the body fat of those animals at the top of the food chain—think polar bear and human, for example. The author succinctly joins the dots regarding the price we are paying for decades of environmental pollution—much of which is farming and food related—when he quotes Michael Lerner saying 'we can't live healthy on a sick planet'. Lerner is a former political scientist turned environmentally aware cancer patient support programme organizer of the world famous Commonwealth Institute, someone with in-depth and joined-up knowledge of ecological causes and effects in industrialized countries.

Besides the synthetic chemical toxins in our food-producing and food-processing systems, the shift involves the typical developed country diet with its pathological ratio of omega-6s to omega-3s, a ratio now scientifically accepted as contributing to inflammatory processes in the body and to specific phases in the cancer cycle. This shift was brought about by government policy actions, engineered in response to food interest lobbying, orchestrated by the Madison Avenue factor and supported by industry-led and -funded research.

But it is not just agriculture that comes under scrutiny in this book. Cancer research in general, with its many warfare metaphors, is also subjected to Servan-Schreiber's challenging gaze. And it appears that the 'culture' of scientific medicine can greatly limit the capacity to 'join up the dots' between specialities. Many experiments tend to look at one agent at a time, an approach that ignores the biological reality of cumulative or symbiotic effects of more than one intervention. The rationale for his criticism equally applies to much of the current research in agriculture: single-factor studies are often valueless when organisms and/or ecology are involved.

In supporting the case for the role of the reader's awareness in choosing a lifestyle that supports good health, the author neatly shows the interconnections that are at the core of ecology. He says 'When we demand food from animals raised with respect for their biological needs, we gradually set off a chain reaction whose effects will be magnified down the

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line ... impacts on rivers and streams. [Through this transformation] we will be contributing to reducing their pollution (with pesticides from cornfields and waste from feedlot-raised animals). Our choice will have an impact on the equilibrium and renewal of land left fallow for the sake of regeneration. It will even have an effect on animals that give us their milk, eggs, and flesh, since they will be in better health when they are fed naturally. Globally, our awareness will have repercussions that extend to our planet's equilibrium ... consuming fewer animal products and demanding healthier food for animals contribute to considerably reducing the greenhouse effect ... '. In the words of Albert Howard, father of organic farming in the UK, 'Healthy soil gives healthy plants, healthy animals and healthy people'. Interestingly, Servan-Schreiber quotes Chief Seattle, that significant repository of traditional indigenous wisdom, who exhorted the white settlers to teach their children 'that the earth is our mother. Whatever befalls the earth befalls the sons of the earth. If man spits upon the ground, they spit upon themselves' and so the Western conventional medic who has awakened to the existence of man's innate healing capabilities, now recognizes that 'all things are connected' in a most unmechanistic way!

I found some details relevant to food and farming deeply disturbing. One example is the statement that researchers have demonstrated that the change in the character of milk since 1950 is responsible for infant obesity. A new omega-6 imbalance in the very nature of milk acts on the growth of both adipose tissue and cancer cells. Even more shocking are the implications of the effect of recombinant bovine growth hormone (rBGH), apart from its genetically engineered nature, as an insulin growth factor (IGF) stimulant. IGF is a major player in stimulation of fatty cells and accelerates growth in malignant tumors. Aggressive use of legal processes by the manufacturers—nothing new for Monsanto—of rBGH will not allow suppliers of non-rBGH milk to label their product as rBGH-free in some US states, a position that echoes the scandal whereby medical and scientific experts for years declared bottle feeding was just as good as breastfeeding and in doing so affected policy decisions. Meanwhile, the IGF created by rBGH ends up in the human food chain; it is not destroyed by pasteurization and the effects of rBGH on humans are not known.

In what is obviously a cry from the author's heart, he remarks on the hidden 'questionable substances introduced in our food since 1940. But these toxic substances are odorless, colourless, and tasteless. Are they 'acceptable' simply because they are hidden? Is this a concern only for those of us already affected once by cancer?' These remarks were made specifically about pesticides, about which there is significant evidence of much chicanery, and corruption—both institutional and corporate—and double talk regarding the state of the pesticide regulatory and control systems worldwide.

The connection between ill-health and industrially produced food is not as firmly established as the link between cancer and tobacco. However, this situation, based on the existing scientific literature, does not take into account how some of this body of information has been corrupted by bad practice (think ghost writers paid by manufacturers of the product under scrutiny), bad processes (think inappropriateness of single factor issues when testing organisms) and the sheer inertia of the prevailing worldview (think 10-year delay in accepting the role of *Helicobacter* in stomach ulcers). And so he spells out the connections as follows: 'As with tobacco, there are very powerful economic reasons for not wanting to know more. Many politicians believe that pesticides promote agricultural productivity, although there is little hard data to support this belief. Some argue that relying on conventional agricultural chemicals protects the economic activity and jobs in farming areas. It also preserves the interests of the chemical industry. Any changes in farming policy to promote practices that respect nature and human health have obvious immediate downsides ... as with tobacco, some of the economic benefits stemming from this change, such as a notable reduction in health-care costs, will only be perceived in the long term. But others may be more immediate such as improvements in water quality and worker health and safety.'

It is worth noting that, since the tobacco sector has come under pressure because of a demand for accountability for its effects, many tobacco companies have moved into the food business and undoubtedly some of their less desirable practices have been transplanted to food business practice. And as for acceptance of inconvenient information, the author succinctly pulls in Al Gore's use of Upton Sinclair's famous quotation 'it's difficult to get someone to understand something when his salary depends upon his not understanding it'. Such a neat way to suggest why inconvenient information may be so often ignored!

It is also worth noting that since the author's first language is French he has ready access to science documentation in the French language, which may not be available in English. From the book's references some significant information sources appear only in French, suggesting that English translations are not available. Some of the more pointed dichotomies in Servan-Schreiber's comments could be Gallic flourishes added to the protective coloration *vis-à-vis* conventional medicine which he appears to take on at times.

And as for my aforementioned partner with the cancer, while he has farmed organically for over 30 years, he reckons that his exposure to synthetic chemicals on the family farm and vineyards in his pre-adult years may be linked to his disease. Indeed, it was an organophosphate-induced serious illness in a farmer friend that inspired him to switch to organic farming in the first place.

Anticancer is indeed a very readable, well-researched and perfectly referenced book with admirable breadth and depth. And its food implications, only a few of which are referred to here, should be incorporated into the thinking of all involved in food and farming matters.

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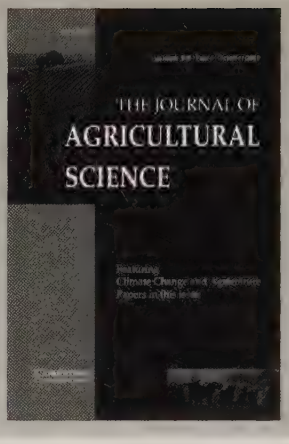

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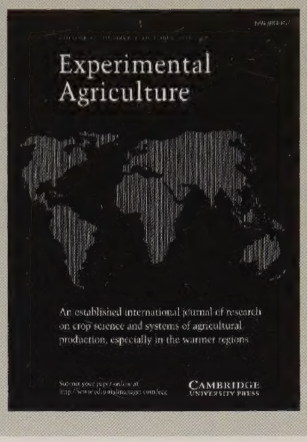
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